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MOISTURE BALANCE IN SOILS OF THE EDMONTON AREA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Moisture Balance in Soils of the Edmonton Area" submitted by Tika Ram Verma, B.Sc. (Agric.), M.Sc. (Agric.), in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The available water capacities of 28 soil profiles in the Edmonton area were determined and correlated with different physical properties of these soil profiles. An attempt was made to evaluate moisture balance patterns by estimating potential and actual evapotranspiration from the available meteorological data at six different stations in the area.

The soil types varied in their available water capacity values because of the existing variation in their physical and chemical properties. On the basis of available water capacity values, the soils were grouped in nine different categories ranging from 2 to 18 inches of available water per four feet.

In comparing the rainfall intensity with the infiltration rates in the soils of the Edmonton area, it was concluded that there is a very small hazard of runoff occurring. Most of the rainfall would be stored in the profile for the use of growing vegetation.

During the summer of 1967, measurements of moisture in ten different soil profiles of the area were made by using the neutron moisture probe; then actual evapotranspiration was calculated from the measured precipitation and moisture changes.

The Penman method was used to estimate potential evapotranspiration from the monthly meteorological data available at six stations in the area.

Linear relationship between actual evapotranspiration as percentage of potential evapotranspiration and available soil moisture

as percentage of total available water capacity was used to estimate the actual evapotranspiration from the potential evapotranspiration available moisture data.

It was found that, during the growing season, soils of the Edmonton area had moisture deficits ranging from 0.6 to 4.9 inches under normal rainfall. The moisture deficit occurred right from the month of May in soils of low available water capacity, and during the later part of the growing season (July-August) in soils of medium available water capacity. Soils with extremely high values of available water capacity had the moisture deficit in the months of August and September.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

APPENDIX

INTRODUCTION

Moisture balance is a hydrological term concerned with the gain and loss of moisture in any area for a specific length of time. For any region the study of moisture balance patterns is necessary for:

(i) The evaluation of land for any particular use,

(ii) Making fertilizer recommendations,

(iii) Consideration of suitability of new crops,

(iv) The assessment of irrigation needs and successful planning of irrigation projects, and,

(v) The assessment of water resources.

The amount of precipitation during the growing season is generally not sufficient to cover the water requirements of cultivated crops under the climatic conditions of the Prairies. For this reason crops depend for a significant part of their needs on the availability of reserve supplies of soil moisture, which in turn is related to the physical and chemical properties of soil profile, and the depth and development of root systems. The soil moisture content varies during the course of the year under the influence of precipitation, runoff, evapotranspiration and drainage. The moisture balance of the soil profile is a critical factor in crop production in Western Canada.

As the rainfall or snowmelt infiltrates into the soil, it is stored within the soil profile, replenishing the soil moisture deficiency created within the root zone by evapotranspiration. Once this moisture deficiency is satisfied, any surplus moisture is lost

by runoff or drains downward beyond the depth of rooting. Depending on infiltration rate, soil moisture, slope, vegetative cover, precipitation intensity and duration, and rate and amount of snow-melt, runoff may occur, although on the Prairies, the chances of runoff are small, especially for summer rainfall.

In areas where potential evapotranspiration exceeds the rainfall for some period of the year but falls below the precipitation for the remaining period, the available water capacity of the soil becomes a very significant factor affecting the moisture balance patterns. In the last few decades much work has been done in studying moisture balance patterns in various parts of the world with great emphasis on potential evapotranspiration. Only a few workers have given sufficient attention to the soil moisture storage in moisture balance studies. The only studies in the Edmonton area have been those by Dr. A.H. Laycock of the Department of Geography, who assumed a wide range of available water capacity of soils in rooting depth, namely 1/2, 1, 2, 4, 6, 8 and 12 inches, and then calculated the moisture deficits that would be likely to occur.

Moisture balance studies in terms of soil moisture availability rather than simply in terms of means of totals of meteorological elements are more meaningful in climatology. The available water capacity, which is determined by physical and chemical properties of soils, varies from one soil type to another. Thus, assumptions regarding the available water capacity for a region, which disregard the variation in physical, chemical and pedological properties of the existing soil types, may likely introduce

significant errors in the estimation of moisture balance patterns.

The main objectives of this study, therefore, were as follows:

1. To study the available water capacities of major soil types in the Edmonton sheet and relate them to the physical properties of the soil profiles,
2. To evaluate relationships between available soil moisture, measured actual evapotranspiration and potential evapotranspiration, and
3. To establish the moisture balance patterns for the Edmonton sheet area based on the data obtained.

soil will remain full of water and a water surplus will occur. On the other hand, if precipitation is always less than the potential evapotranspiration or water need, moisture will be limited and a moisture deficit will exist. Under normal conditions both of these conditions will occur during the course of a year or several years at a place so that a comparison of the potential evapotranspiration with the precipitation will show both a wet or cold season in which water need is less than the available precipitation and a dry or hot season in which the water need exceeds the precipitation. Under such circumstances the following periods usually occur: a period when precipitation is greater than the moisture demand and a moisture surplus accumulates; a dry period, when the moisture in the soil is being used by the plants, the soil moisture storage is diminishing and a moisture deficit occurs; and a remoistening season, when precipitation exceeds water use and the soil moisture storage is replenished. The values of moisture surplus and deficiency as well as of the other factors of the water balance can be computed by means of a simple water balance book-keeping procedure.

Constituents of Moisture Balance

Slatyer (1961) stated that the evaluation of the water balance at any time can be achieved by utilizing a simple equation:

Initial soil moisture storage + Incoming water = Final soil moisture storage + Outgoing water.

Also, he reported that in arid and semi-arid climates, outgoing water is represented by evapotranspiration.

REVIEW OF LITERATURE

Moisture Balance

Since the early forties, there has been an increasing realization that drought cannot be defined in terms of deficiency and variability in the precipitation alone. Study of the precipitation alone fails to give an idea about the amount of water that is needed and the amount of water that might be available during the growing season.

Defined

The term moisture balance came into the picture, when Thornthwaite (1948) made an effort to give quantitative expression to the climatic factors which determined the relative moistness or aridity of a place. He asserted that the moisture conditions in any area could not be determined from data on precipitation alone, but rather from a balance between the precipitation, which adds moisture to the area, and the evapotranspiration, which removes moisture.

Thornthwaite and Mather (1955) defined moisture balance thus: "When the potential evapotranspiration is compared with the precipitation and allowance is made for the storage of water in the ground and its subsequent use, periods of moisture deficiency and excess are clearly revealed and an understanding of the relative moistness or aridity of a climate is obtained".

Mather (1959), having used Thornthwaite and Mather's (1955) definition, discussed a number of aspects. If the amount of precipitation is always greater than the evapotranspiration, the

Downes (1963) mentioned that the components of water balance-precipitation, evaporation, transpiration, surface runoff, and infiltration can be expressed by the equation:

$$P = E + T + R + I$$

where, P = precipitation;

E = evaporation from soil and plant surfaces;

T = plant transpiration of water extracted from the soil;

R = surface runoff; and

I = infiltration into the soil.

The soil moisture increment or infiltration (I) can be disposed of in three ways which are expressed by the following equation:

$$I = W + S + A$$

where, W = loss to underground by deep percolation;

S = seepage or laterally moving water; and

A = the increment to the possible soil moisture storage.

The water balance model, according to Wiser (1965) may be expressed as:

$$SMC_f = SMC_i + P - ET - \text{Excess},$$

in which SMC_i and SMC_f are soil moisture contents at the beginning and end of the day, respectively; P is precipitation that may include irrigation; and ET is evapotranspiration.

Ayers (1967) discussed in detail the factors affecting moisture balance. In his equation,

$$M_t = M_o + (P - E) + (I_h - O_h) + (I_v - O_v) + (I_s - O_s)$$

M_t is the soil moisture content at time t,

M_o is the soil moisture content at time $t = 0$,

P is the rainfall, condensation, and/or snowmelt from time $t = 0$ to $t = t$,

E is the evapotranspiration from time $t = 0$ to time $t = t$,

I_h and O_h are respectively horizontal inflow and outflow moisture flux components from $t = 0$ to $t = t$,

I_v and O_v are respectively the vertical inflow and outflow moisture flux components from $t = 0$ to $t = t$,

I_s and O_s are respectively the surface inflow and outflow components from $t = 0$ to $t = t$.

He claimed that the relative significance of the various components vary from time to time.

Holmes and Watson (1967) measured the various constituents of water budget under irrigated pastureland in southern Australia. They concluded that in the arid and semi-arid regions, the main income is from rain and irrigation; and the major expenditure is through evapotranspiration.

Stern (1967b) also gave an equation to define the constituents of water balance. In his equation:

$$R + I = E_t + O + \Delta S + U$$

R is rainfall, I is irrigation, E_t is evapotranspiration and includes evaporation and transpiration, O is surface runoff, ΔS is the increase in water content and U is through-drainage beyond the terminal depth.

Meteorological Studies

Precipitation

Linsley and Kohler (1951) discussed the nature and extent of variation in rainfall intensity and total amount within a watershed area. They stated that the variation in precipitation is influenced by elevation, slope, aspect and other factors.

The variation in precipitation catch because of differences in types of commonly used gauges seldom exceeds 5 percent. The variation at a particular site because of differences due to wind may exceed 50 percent when wind speeds are greater than 20 miles per hour. The upward movement of air over the gauge reduces the fall of precipitation, particularly snowflakes, into the gauge (Heatt and Schloemer, 1955).

Myers (1959) proposed a mathematical solution for the determination of average watershed precipitation. He claims that his method makes possible the evaluation of average precipitation for watersheds, regardless of irregularity in topography. Once the equations are established in the study of one storm, computations for analyses of other storms of any duration or intensity can be made very rapidly.

A certain amount of the precipitation is intercepted by vegetation. In the case of rain, only a small amount can accumulate on the plant leaves before it begins to run off. However, the canopy may redistribute the rain fall in a pattern different from that in which it originally falls. The amount of redistribution of this through-fall varies with the type of canopy (Stout and

McMahon, 1961).

Stoekeler (1962) in reviewing the previous work stated that more snow can be held by vegetation because snow can pile up to a considerable thickness. The distribution of snowfall can be affected on a much larger scale than rainfall because of the tendency of snow to drift due to variation in wind velocity.

James (1964) noted that the higher the wind velocities during precipitation, the greater the catch on the leeward side of a hill. During a period of snowfall with moderate winds, the distribution was reversed.

Gardner (1965) in a review said that the fate of precipitation after it reaches the earth may be considered in a manner analogous to the energy budget. A certain fraction of the precipitation is intercepted by the plant canopy and evaporated without reaching the soil surface, part infiltrates into the soil and part runs off over the surface of the soil, eventually finding its way to a stream.

Palmer (1965) stated that the amount of precipitation required for the near-normal operation of the established economy of an area during some stated period is dependent on the average climate of the area and on the prevailing meteorological conditions, both during the preceding month and during the period in question. Also, he demonstrated the method for computing the required precipitation. The difference between the actual and the computed precipitation represents a fairly direct measure of the departure of the moisture aspect of the weather from normal.

Potential evapotranspiration

Concept

Potential evapotranspiration was defined by Thornthwaite (1944) as "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation".

Thornthwaite (1954) re-examined his concept and stated that it was necessary to specify a number of plant and climatic conditions in order to define potential evapotranspiration. Thus, first, the albedo of the evaporating surface must be a standard; second, the rate of evapotranspiration must not be influenced by the advection of moist or dry air; and finally, the ratio of energy utilized in evaporation to that in heating the air must remain essentially constant.

Thornthwaite and Mather (1955) defined potential evapotranspiration as "the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of vegetation". They point out that since the rate of evapotranspiration is dependent on the moisture content of the soil, it becomes necessary to assure that the surface soil does not dry below "field capacity", because otherwise the ratio of evaporation heat loss to the total heat loss could not remain constant. Also, they mention that the potential evapotranspiration depends on:

(a) the external supply of energy to the evaporating surface, principally by solar radiation;

(b) the capacity of air to remove the vapor, i.e., on wind

speed, turbulent structure and the decrease of vapor concentration with height; and

(c) the nature of the vegetation, especially as regards its capacity to reflect incident radiation, the extent to which it fully occupies the soil, and the depth of its root system.

Penman (1956) defined potential evapotranspiration as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water". He drew four generalized conclusions about potential evapotranspiration:

(a) For complete crop covers of different plants having the same reflection coefficient, the potential evapotranspiration rate is the same, irrespective of plant or soil type;

(b) The rate of potential evapotranspiration is determined by prevailing weather;

(c) The rate of potential evapotranspiration cannot exceed the evaporation from an open water surface exposed to the same weather; and

(d) Maintenance of maximum transpiration rate is a necessary condition for the maintenance of maximum growth rate.

Blaney and Criddle (1962) called potential evapotranspiration the consumptive water requirement and defined it as "the amount of water potentially required to meet the evapotranspiration needs of vegetative areas so that the plant production is not limited from lack of water."

Bouchet (1965) mentioned that it is an accepted principle

that potential evapotranspiration is the maximum evapotranspiration of a plant cover where energy is the only limiting factor to be considered.

Factors affecting potential evapotranspiration

Thornthwaite (1944), defining the concept of potential evapotranspiration, mentioned that when water was plentiful, the rate of water loss from soil and vegetation was determined by meteorological factors and that the factors altering the effect of meteorological factors would certainly affect the amount of water loss from soil and vegetation.

Penman (1948) mentioned two theoretical approaches to evaporation from saturated surfaces, the first being on an aerodynamic basis in which evaporation is regarded as due to turbulent transport of vapour by a process of eddy diffusion, and the second being on an energy basis in which evaporation is regarded as one of the ways of degrading incoming radiation.

Atmospheric elements whose influence on transpiration has been studied include solar radiation, air temperature, wind and humidity. These factors are all interrelated. Although solar radiation is the basic factor, there seems to be a closer parallelism between air temperature and transpiration. The temperature of the transpiring part is most closely related to the rate of transpiration. Determinations by Thornthwaite (1948) showed that potential evapotranspiration is high in the southern parts of the United States and low in the northern part and it varies greatly from winter to summer. From observations it has been found that when adjustments are made

for variation in day length, there is a close relation between mean monthly temperature and potential evapotranspiration.

Thornthwaite and Mather (1954) reported that, under conditions of continuously optimum soil moisture, the daily water use of different crops with generally the same physical characteristics can be well expressed by meteorological and solar factors without considering the type of vegetation. This does not mean that all vegetation under potential evapotranspiration conditions uses the same amount of water but merely that differences in water use between different types of vegetation possessing similar physical properties becomes less significant when the soil moisture content is high. It must be remembered that this partial lack of dependence on crop factors is true only when potential evapotranspiration is considered.

When potential conditions actually exist in arid regions, the meteorological conditions controlling the rate of water loss are themselves so altered as, in turn, to change the actual rate of evapotranspiration (Crowe, 1957).

Green (1958) reported that the grouping together of measurements taken at different sites with somewhat different plant covers means that the results can only give an approximate indication of the effect of the size of irrigated area on the rate of potential evapotranspiration. He mentioned also that the width of an irrigated border area up to 50 meters has a very significant effect but that after 200 meters, any further changes in the distance to the upwind border of the irrigated area has little effect on the rate of water loss.

Tanner and Lemon (1962) found that where water is plentiful, the evaporation process is restricted neither by plant nor soil factors but by the supply of energy available. Under certain circumstances, plants are able to use more energy for evaporation than is supplied by the radiant energy.

Sellers (1964) described the quantitative relationships which exist between potential evapotranspiration in an arid region and various meteorological factors. At Yuma, Arizona, a 50 percent increase in the relative humidity above the climatological average reduces the potential evapotranspiration by 10 to 15 percent, the estimated annual total dropping from about 2200 mm. to 1975 mm.

Stanhill (1965) concluded from his results that the size of irrigated area and crop height affect the potential evapotranspiration in arid and semi-arid conditions and, therefore, potential evapotranspiration can be considered only as independent of the crop characteristics if the area receiving the daily irrigation is very large.

Baier and Robertson (1967) found that the potential evapotranspiration varies according to the stage of the plants or the estimated percentage ground cover. Water from bare soil evaporated at approximately 70 to 90 percent of the potential evapotranspiration rate. Evapotranspiration from an actively growing crop, completely covering the ground and adequately supplied with water, may even exceed the potential evapotranspiration rate estimated from instruments or climatological data.

Measurement of potential evapotranspiration

The evapotranspirometer, when operated properly, i.e., when watered sufficiently so that there is no moisture deficiency and no appreciable moisture surplus in the soil of the tank, and when exposed homogeneously within a protective buffer area of the proper size to eliminate the effects of moisture advection, is an instrument which should give reasonably reliable values of potential evapotranspiration. Great care must be taken in operation of the instrument and standardized soil, vegetation, cultivation and watering practices must be maintained on the tanks in order to insure comparable results from one installation to another. A large number of instruments supposedly giving measurements of the evaporativity or the evaporative power of the air are available. They range in size from the Livingston atmometer and the Piche evaporimeter, or the small Japanese water pans which are exposed within a weather shelter, to the large water or soil pans some of which are 10 or more meters in diameter exposed to the free air. Because of their size and shape, exposure, and method of operation, these instruments are influenced differently by the surroundings. As a result of this varying influence of the environment on these instruments, none can be said to give a reliable measure of evaporation. Even when these instruments are exposed under moist conditions which minimize the effect of size, shape, and other characteristics of the instrument, there is no assurance that the potential evapotranspiration is being measured with accuracy (Thornthwaite and Mather, 1954).

Sanderson (1949) reported the potential evapotranspiration data from the evapotranspirometer installation in Toronto, Ontario. The evapotranspirometers were put under different grass covers and optimum moisture conditions were maintained.

Garnier (1952) reported a simple apparatus for measuring potential evapotranspiration. He stressed that the area immediately surrounding the apparatus should be kept well watered so that the microclimate above the tank and its surrounding is as nearly similar as possible.

Mather (1959) pointed out that the failure to maintain ideal conditions in an evaporimeter installation can result in either too much or too little water loss. The condition of the vegetation is most important. If the vegetation in the tank stands up prominently above the surroundings, the observations of the water use are probably worthless and should be disregarded.

Pelton (1961) reported the use of a lysimeter for measuring potential evapotranspiration by maintaining representative cover and optimum moisture conditions.

McIlroy and Angus (1964) presented the results of the first three years of operation of a multiple-large-weighed-lysimeter installation. They reported that the evaporation from well-watered grass (potential evaporation) consistently exceeded that from free water, and even more than that from wet soil. They suggested the desirability of using lysimeter results to calibrate simpler methods of determining evaporation for subsequent routine use.

Hudson (1965) reported that evapotranspiration gauges of

many different patterns may be used to measure potential evapotranspiration. Despite their drawbacks, such gauges have reached a stage where they can be used with reasonable reliability to measure evapotranspiration rates from the sample of soil and plants which they contain.

Evapotranspirometers can be adapted to permit measurement of potential evapotranspiration. This involves keeping the soil in the root zone near field capacity. The device favored by C.W. Thornthwaite and Associates is the potential evapotranspirometer, in which a constant water table is maintained by means of a simple carburetor feed line. There is some advantage, however, in maintaining a water supply by means of surface irrigation. This more nearly simulates natural rainfall, and permits a more realistic moisture-tension profile inside the evapotranspirometer. The chief problem with all such instruments is that of maintaining an adequate buffer of watered, similar vegetation around them. In dry areas such a buffer, to prevent an oasis, must be prohibitively large (Thornthwaite and Hare, 1965).

Bay (1966) developed a bottomless evapotranspirometer (10 feet in diameter) to use in organic soils and tested under open bog conditions. The weekly water losses from two evapotranspirometers compared favorably with pan evaporation and with potential evapotranspiration calculated from climatological data.

Estimation of potential evapotranspiration

Penman (1948) attempted to combine the two approaches, namely

aerodynamic and energy balance, in a simple equation to estimate evaporation from a hypothetical open water surface. The conversion from evaporation from a water surface to potential evapotranspiration is achieved by means of empirically developed coefficients.

Thornthwaite (1948) assumed that the relation between mean monthly temperature and mean monthly evapotranspiration is an exponential one, i.e. on logarithmic paper a straight line relationship is obtained. The slope and intercept of this line are determined by the "heat index" of a location, which in turn depends on the mean monthly temperature.

Sanderson (1949, 1950) has reported that the three years' results from the Toronto evapotranspirometers verify the Thornthwaite formula for computing potential evapotranspiration at this latitude. The Thornthwaite formula did not consistently overestimate potential evapotranspiration for any one month or season during the three years, nor underestimate it for any other.

Van Wijk and de Vries (1954) concluded from their studies in the Netherlands that no method based on monthly temperature can be expected to give reliable results for different regions. The temperature of the air lags behind solar radiation at moderate and high latitudes and, therefore, the amount of energy available for evaporation in the spring is quite different from that available in autumn, if periods with same temperature are compared. The energy available for evapotranspiration can be calculated by applying the theory of heat exchange (including radiation) to a wet body of the same shape as the vegetation cover.

Thornthwaite and Mather (1955) justified the Thornthwaite method as follows: "The temperature can serve as an index to potential evapotranspiration because there is a fixed relation between the net radiation used for heating and that used for evaporation when conditions exist to achieve the potential rate". They claim that the mean air temperature is relatively unaffected by the introduction of conditions of potential evapotranspiration.

Penman's (1948, 1956) combination of energy balance and aerodynamic approach gives the evaporation from a hypothetical open water surface as a function of the net radiation and the saturation deficit adjusted for wind as a measure of the drying power of the air.

Van Bavel (1956) reported that the formula of Thornthwaite is based on experience with watersheds in the central and eastern United States and has limited value. Where temperature and radiation are strongly correlated such as in temperate, continental climates, the formula works well. In the Southern latitudes or in maritime climates, the formula does not seem to apply nearly as well. Further, the formula lags three or four weeks in the spring and summer because air temperature lags behind radiation, which really determines evapotranspiration. He modified Penman's formula slightly, and used it in preference to estimate potential evapotranspiration.

Maurice and Covey (1957) reported that the majority of equations involving the concept of potential evapotranspiration or consumptive requirement tend to assume a homogeneous soil moisture regime infinite in horizontal extent, and therefore, it has been difficult to apply these equations to irrigation practice, which

obviously must create areas of above normal moisture.

Holmes and Robertson (1958, 1959) found a conversion factor of 0.0034 inches for evapotranspiration from irrigated fields for each cubic centimetre of latent evaporation measured by the Bellani plate atmometer.

Rijtema (1958) stated that some of the modern formulae used for calculating potential evapotranspiration from meteorological data give results as accurate as those obtained from experimental data from weighable grass-covered lysimeters well supplied with water.

Levine (1959) in a review said that the Blaney-Criddle, Thornthwaite and Penman methods are designed to give estimates of maximum evapotranspiration, implying a completely vegetated area with soil moisture not limiting. In addition they are limited to relatively large areas of uniform vegetation. Though each of these methods has been used with success in certain areas, care should be exercised in the widespread application of any one.

Mather (1959) stated that the Thornthwaite formula provides reasonably reliable values of potential evapotranspiration. The calculated values compare well with those obtained from actual measurements in a humid area.

Pelton, King and Tanner (1960) in evaluating methods for determining the potential evapo/transpiration from mean temperature concluded that "The Thornthwaite method fails for short period estimates principally because mean temperature is not a suitable physical measure of the energy either available for or used in

evapotranspiration. The high mutual correlation of both evapotranspiration and mean temperature to net radiation that can be used advantageously for monthly, growing season, and annual estimates, does not exist over short periods."

The correlation between the readings of shaded evaporimeters and potential evapotranspiration is at the best very poor. These apparently aberrant results can be explained by abstract analysis of the phenomenon in terms of "boundary layer" mechanics which shows that, to arrive at the potential evaporation readings, correction factor must be introduced, based solely on temperature (Bouchet, 1961).

Stanhill (1961) compared under arid conditions eight methods of calculating potential evapotranspiration. Of the climatic formulae tested, that by Penman gave the best results for monthly and weekly periods, followed by the formula by Thornthwaite, Blaney and Criddle, and Makkink. Potential evapotranspiration results from tanks and pans were equally good as those from Penman's formula, whereas those derived from solar radiation estimates and from Piche's evaporimeter were the least accurate. The discrepancies between the methods were the same whether weekly or monthly periods were compared. The weekly estimates from all methods were, however, less accurate, the error being two to three times larger than that of the corresponding monthly estimates. The experimental results clearly indicated that the empirical formulae are satisfactory only if the local correction factors are known.

Decker (1962) compared Penman and Thornthwaite derived estimates of evapotranspiration with the measured evapotranspiration from corn. Both methods of estimation approximated the measured values with the method of Penman giving a lower variability.

Baier (1963) used the long term averages of 44 weather stations in South Africa and determined the relation between monthly potential evapotranspiration as computed by Thornthwaite's method and evaporation from a Symon's tank. Because air temperature lags behind radiation during the period of increasing radiation, a lower value for Thornthwaite's potential evapotranspiration was found to be associated with a given tank evaporation than during the time of decreasing radiation. Potential evapotranspiration as determined by the Popov evaporimeter also exceeded by far Thornthwaite's estimates. He emphasized the need for direct determination of potential evapotranspiration in dry climates such as those prevailing in South Africa.

Smith (1964) calculated the annual, seasonal and monthly values of potential evapotranspiration for a 26-year period from the Penman and Thornthwaite methods, and compared these with measured water evaporation. Consistent and significant differences were noted between the various results and generalization drawn regarding the overall performance of these formulae in northern England. He found that in a humid British climate Thornthwaite's long-term annual potential evapotranspiration estimates amounted to 123 percent of measured tank evaporation while Penman's potential

evapotranspiration estimates amounted to only 84 percent of measured tank evaporation. During the year, Thornthwaite's formula exaggerated estimates in the summer months, where Penman's formula underestimated potential evapotranspiration in autumn. He concluded from this study that open water evaporation provides a better measure of the monthly and seasonal evaporating power of the air than estimates based on the two formulae.

Baier and Robertson (1965) used maximum temperature as a manifestation of the net radiation, temperature range to reflect the vapor pressure deficit and solar energy at the top of the atmosphere to indicate the changes of radiation with season and latitude. With the use of these data in Penman's formula, they claimed better potential evapotranspiration estimates.

Bouchet (1965) proposed evaluation of potential evapotranspiration on the basis of measured screen evaporation (eg. with the Piche evaporimeter), corrected in accordance with air temperature and dew-point. By combining the Penman formula and that of corrected screen evaporation, a daily evaluation of potential evapotranspiration is obtained from the simple meteorological data recorded in a standard meteorological screen.

Brutsaert (1965) compared the monthly evapotranspiration data obtained by various methods for the valley of Ruzzi in the eastern Congo Republic. Best agreement was noted between evaporation, as measured with a pan, and calculated with Penman's equation. The Blaney-Criddle and Thornthwaite methods did not have an adequate response to changes in evaporation potential,

since temperature and day length varied little.

Papadakis (1965, 1966) developed a formula to estimate potential evapotranspiration. He claims that his formula integrates the effects of radiation, advection and air dryness on potential evapotranspiration when averages of over 10 or more days are considered.

Stern and Fitzpatrick (1965) in Australia found that the empirical relationships based solely on temperature in a climate of marked seasonal contrast in atmospheric moisture content have no practical value as short-term predictors during the dry season and little value for intervals as short as 5 days during the wet season. On the other hand, a vapor pressure deficit term calculated from maximum temperature was found an excellent predictor of Penman's potential evapotranspiration as well as tank evaporation. Even Piche's evaporimeter readings gave sufficiently accurate estimates provided that a relationship appropriate to the season had been identified.

Evapotranspiration from alfalfa correlates best with meteorological elements when the crop is transpiring at the potential rate, according to Hobbs and Krogman (1966). The rate will not be reached until the crop has attained full ground cover and is adequately supplied with moisture. Under these conditions each of three commonly used evaporimeters provide good, direct estimates of plant water use. Of the more basic meteorological observations, there is ample justification for the use of temperatures in prediction equations. Where more precise determinations involving

the influence of other meteorological parameters are required, simple correlation does not adequately define the relations. Even though individually some parameters may not exert a large influence, in combination with other factors they may make an appreciable contribution.

Using a combination of a surface energy balance equation and an approximate expression of water vapor and sensible heat transfer, Van Bavel (1966) formulated an equation relating potential evapotranspiration to net radiation, ambient air properties, and surface roughness. As an improvement over an earlier Penman version, the proposed model contains no empirical constants or functions. Tests of the model in Phoenix, Arizona, using open water, wet bare soil and well watered alfalfa, show excellent agreement of calculated and measured values on an hourly and daily basis under a variety of circumstances.

Eagleman (1967) has also given a formula for estimating evapotranspiration rate from temperature and relative humidity data. Results of some tests of the accuracy of his equations indicate that it is better than other equations based on a similar number of variables. The accuracy was not as good, however, as equations requiring more variables for their utilization.

Laycock (1967) in his studies of water deficiency and surplus patterns in the Prairie Provinces used Thornthwaite's procedure for estimating potential evapotranspiration. He used the Lowry-Johnson and Blaney-Criddle procedures also for estimating potential evapotranspiration and concluded that neither provides

a water balance for the year and if Thornthwaite's moisture storage allowances for spring are employed, both show patterns very similar to those based on the Thornthwaite procedure.

Stern (1967a) calculated the potential evapotranspiration for each day by Penman's method using net radiation and other meteorological data. The overall ratio potential evapotranspiration/evaporation was 0.88 although for most intervals immediately after irrigation it was greater than unity.

Actual Evapotranspiration

Under natural conditions, actual evapotranspiration primarily depends on the available energy or the atmospheric demand as reflected in the potential evapotranspiration and the availability of soil moisture.

Factors affecting actual evapotranspiration

Several plant and soil factors interact to affect the direct evaporation of water from the soil and evaporation of the water from the plants as a result of transpiration processes. Tanner and Lemon (1962) gave a concise review. Soil factors include the moisture content, the soil moisture suction, and the water transmission characteristics. The plant factors include the leaf area, root proliferation, plant type, and perhaps physiological age. Leaf area appears to be of greatest importance directly as a surface to evaporate water and indirectly as a cover to shade the ground. The amount of radiation utilized in evapotranspiration can vary from zero, when no water is available, to an evaporation

potential exceeding the net radiation (and even the solar radiation) received, when water is plentiful.

Penman (1949) reported the dependence of transpiration on weather and soil conditions. The soil factors determine the rate of transpiration when the moisture level in soils drops well below field capacity.

Staple and Lehane (1954) found that mean free water evaporation bears little relationship to evapotranspiration from wheat plants grown under the semi-arid conditions of Swift Current, Saskatchewan. When wheat was grown under moisture deficit, soil moisture influenced evapotranspiration much more than did the evaporative conditions of the atmosphere. The real (actual) evapotranspiration of grassland falls below the potential evapotranspiration when the soil is drying. The rate of reduction depends on the moisture tension of the soil and on the magnitude of the potential evapotranspiration as a measure for evaporation. The actual evapotranspiration may keep up with the potential evapotranspiration of a definite intensity; the wetter the soil, the higher the intensity at which reduction begins to occur.

In a peat soil the effect of soil moisture tension on the reduction in evapotranspiration was smaller than in a clay soil (Makkink and Van Heemst, 1956).

Slatyer (1956) from his experiments conducted in northern Australia, claimed that his data illustrated the progressive decline in actual evapotranspiration which occurred as the amount of available soil moisture decreased.

Army and Ostle (1957) in a study involving over 25 years of crop and weather data at two stations in the Northern Plains of Montana found that the evapotranspiration of dryland spring wheat was negatively correlated with free water evaporation. In years of high temperature and low rainfall, i.e., high free-water evaporation, reduced crop growth and an inadequate supply of soil moisture resulted in low evapotranspiration. Cultural practices and geographic location influenced the amount of evapotranspiration per unit of free-water evaporation. The greater amount of free-water evaporation always resulted under fallow rather than under continuous wheat. The degree of association between free-water evaporation and evapotranspiration ratio was apparently reduced by limited soil moisture supply. They also point out that the effect of cultural practices, geographic location, and limited moisture supplies on the magnitude of evapotranspiration per unit of free-water evaporation detract considerably from the value of free water evaporation measurement as an indication of water use by wheat plants under semi-arid conditions.

Evapotranspiration, as described by Lemon et al. (1957), is a function of soil, plant and meteorological factors. They found that evapotranspiration is controlled by soil moisture tension, physiological factors, the relation of soil moisture of an irrigated area to that of its surroundings as well as purely meteorlogical factors of radiation, wind, air temperature, and humdity.

Angus (1959) in his review "Water and its relation to

soils and crops" mentions the influence of crop characteristics on evapotranspiration. The length of the time the crop is in leaf is the main effect of crop type on evapotranspiration. The percentage of ground cover also has an important effect on water use.

Monteith (1959) found the difference in evapotranspiration caused by differences in reflection quite modest, certainly less than 25 percent. For humid regions where evapotranspiration is primarily dependent on net radiation, an extreme change of 15 to 30 percent in reflection would cause a change in evapotranspiration of less than 25 percent.

Tanner *et al*. (1960) reported studies of evapotranspiration on corn. On a given soil total evapotranspiration depends on the water available to the plants, as well as that available at the soil surface, and upon the total radiation above the corn and the soil surface. When water is readily available to the plants and at the soil surface, maximum evapotranspiration obtains. Under these conditions, plant population and practices which affect the radiation at the soil surface have little effect on total evapotranspiration. For example, the corn on high population planting will intercept more energy than that on a low population resulting in higher transpiration. However, the evaporation from the soil surface will be in proportion to the energy transmitted to the soil. Thus the evaporation from the low population field is higher than that from the higher population, making up for the difference in the transpiration. If the soil surface is dry so that the evaporation is limited by moisture supply at the soil surface, a

different picture develops. In this case the transpiration from the high population corn will again exceed that from the low population.

Bahrani and Taylor (1961) found that the ratio of actual to potential evapotranspiration decreased curvilinearly with the soil matric potential. Most of the reduction took place at high potentials (lower matric suctions). Daily net radiation decreased following alfalfa hay harvest and increased again following irrigation.

Fritschen and Shaw (1961) reported the existence of different microclimates in plastic covered plots and natural plots. Their conclusion was based on the results of soil temperature measurements, net radiation measurements and physiological maturity of the corn plants. The evapotranspiration and evaporation from corn were also variable.

Denmead and Shaw (1962) concluded that the actual evapotranspiration decreased with decreasing soil moisture content and increasing potential evapotranspiration. Average soil suction in the root zone, when the actual evapotranspiration rate fell below the potential evapotranspiration rate, varied from 12 bars when the potential evapotranspiration rate was 1.4 mm. per day to 0.3 bar when the potential rate was 6 to 7 mm. per day.

Evapotranspiration by irrigated corn in Alabama, as reported by Doss *et al*. (1962), increased with plant development to a maximum of 0.3 inch per day at dough stage and afterwards decreased with physiological activity of plant growth. The ratio of evapotranspiration by corn to open pan evaporation varied from

.38 at emergence to 1.12 during early dough stage, then declined to 0.95 at grain maturity.

Viets (1962) in reviewing the effects of fertilizers on the use of water mentions that since agriculture in desert and semi-arid areas is subject to advection and even crops in humid areas for short periods of time are similarly subject to turbulent heat transfer, no one can categorically say that a fertilized and larger crop does not use more water. On the other hand, it is safe to conclude that in a field a crop twice as large does not require twice as much water and its consumptive use is about the same or is only slightly increased. Where fertilizers are needed and water is available in the lower profile depths, fertilization, in general, increases extent and depth of rooting, and, thereby, evapotranspiration under semi-arid conditions.

Dreibelbis and Amerman (1964) reported the effects of various soil and agronomic factors on the magnitude of evapotranspiration. They have shown from their lysimeter data, that the magnitude of evapotranspiration varies for corn, wheat and meadow.

The quantity of summer soil moisture lost from logged forest opening (Ziemer, 1964) was related to the length of time since the creation of opening. This was in the subalpine forest zone of the Sierra Nevada at an elevation of 6000 to 7000 feet. Soil moisture was found to be uniformly near field capacity in all plots in early June. Later, soil moisture was lost most rapidly from the forested parts of the plots and at progressively slower rates toward the center of the openings. The rate of the

moisture loss was greatest in the early summer and then decreased as the availability of soil moisture decreased. Maximum soil moisture depletion occurred in early September, nearly all the available soil moisture being depleted from the forest. The quantity of residual soil moisture depletion, in openings one year old, were found to have 6.9 inches more soil moisture per four feet of soil than the surrounding forest had, which is an expression of the quantity of moisture saved as a result of the logging operation. The openings five years old, the saving decreased to 2.9 inches, after 10 years to 1.2 inches, and after 12 years to 0.7 inch. A projection of the regression indicates that the moisture saving at maximum depletion will become negligible 16 years after cutting.

Eagleman and Decker (1965) found the regression between soil moisture deficit and the actual evapotranspiration curvilinear with a correlation coefficient of .72. A negative linear regression described the relationship between the soil moisture potential and the actual evapotranspiration with a simple correlation coefficient of -.74. The relationship between unsaturated conductivity and the relative evapotranspiration rate was investigated by them in a laboratory experiment which showed that plants growing in the soil wilted as unsaturated conductivity dropped from 8.97 cm. per day per joule to 0.77 cm. per day per joule.

Ekern (1965) reported that the maximum evapotranspiration for pineapple occurs when the plants are small and direct evaporation from soil is great. The summer evapotranspiration rate following planting in October is about one-half to one-third the evapotrans-

piration at planting, in spite of the fact that free-water evaporation from the pan doubles from winter to summer.

According to Ferguson (1965), mean weekly evapotranspiration by spring wheat at Brandon, Manitoba, was dependent on the stage of development of the crop. It increased from 0.70 inches per week at the 3-leaf stage to 1.45 inches per week at the flowering stage and decreased to 0.60 inch per week as the crop reached maturity. He found that evapotranspiration correlated positively with Bellani plate evaporation when the soil was moist to the surface and correlated negatively when the surface soil was dry but total soil moisture was greater than 50 percent of field capacity. When the soil moisture was less than 50 percent of field capacity, evapotranspiration was not correlated with Bellani plate evaporation. The evapotranspiration was correlated positively with total soil moisture plus rainfall. This emphasizes the importance of moisture stress in limiting evapotranspiration in a semi-arid region.

Krogman and Hobbs (1965) on the basis of their results from a plot experiment, in which three levels of irrigation were applied during three successive summers, concluded that the average daily rates of evapotranspiration by alfalfa ranged from 0.05 to 0.36 inch per day and the maximum evapotranspiration rate was associated with complete ground cover.

Ekern (1966) reported that despite the potential evaporation, actual evaporation from Wahiawa Low Humic Latosol measured by hydraulic lysimeters is very low under field conditions. Thus, the evaporation from Latosol at field moisture content is only one-

third the rate from a pan. The heavy clay is so strongly aggregated that the water release for low values of soil moisture suction is determined by the aggregates rather than by the mechanical composition of the soil. Moreover, the mineralogical and aggregate composition of the soil make the material an excellent thermal insulator and the consequent restriction of heat flow also reduces the rate of evaporation since much of the water movement within the unsaturated Latosol is in the vapor phase along temperature gradients.

Fulton (1966) used floating lysimeters in Ontario to measure evaporation from bare soil and evapotranspiration from a potato crop during three consecutive seasons and found that the evaporation from the bare soil amounted to 87.5 percent of the water lost by evapotranspiration from the crop. Moisture loss from the bare and cropped areas differed only for a short period of time at mid-season. He concludes that, during this period, plant roots utilized moisture stored at depths beyond which water was available for evaporation. Later in the season when this source of water was exhausted losses from the two areas were again equal.

The measurement of evapotranspiration under salt cedar in Arizona showed a diurnal wave with a maximum loss of water in early afternoon of hot summer days (Van Hylckama, 1966). The losses from bare tanks showed two maxima with a sharp drop during the middle of the day.

Stern (1967a) mentioned that the rate of evapotranspiration is a function of soil moisture, declining rapidly as the available soil moisture falls below 60 percent. Because of the high

variability in the estimates of evapotranspiration it was not possible to evaluate precisely the influence of growth stage on evapotranspiration. Although there was evidence that the evapotranspiration varied with the stage of growth, meteorological factors were a dominant influence because of the high watering regime. Overall, a crop planted in the wet season used little more water than a crop planted in the dry season. After the maximum leaf area index had been reached, evapotranspiration in the wet season crop declined more rapidly and fell to a lower value than evapotranspiration during the corresponding period in the dry season crop. He also discusses the possible interactions of some of the factors influencing evapotranspiration in a crop and concludes that during the periods of rapid height increases, particularly when ground cover was incomplete, crop surface roughness enhanced evapotranspiration.

Van Bavel (1967) estimated the soil water potential to be 4 bars when stomatal control of evaportranspiration became noticeable. Qualitatively, this observation supports other evidence on the relation between soil water availability and water use by plants.

Sturges (1968) found the evapotranspiration from bog higher than from the evaporation from pan. He explains it on these bases: the peat surface is a good sink for solar radiation; a greater proportion of the sun's energy received at the bog surface is available for evaporation than is available for a water body; and evapotranspiration from wet lands is not limited by the availability of water but by atmospheric conditions.

Measurement of actual evapotranspiration

Harrold and Dreibelbis (1958) used weighable lysimeters to measure evapotranspiration. In their experiment weighing was accomplished by means of a specially devised scale.

Morris (1959) measured actual evapotranspiration with a recording weighing machine which had an accuracy of 5 gms.

Pelton (1961) described the use of hydraulic weighing lysimeters in the measurement of actual evapotranspiration, and concluded that the lysimeters can be used to measure actual evapotranspiration with a reasonable accuracy.

Van Bavel (1961) presented a review of various methods to determine the evapotranspiration rate under field conditions. In his review, it is shown that data collected by suitable lysimetric methods are the only ones that exist in quantity and that, at the same time, can be considered reliable. He reviewed the conditions also which must be met by a lysimeter installation for the accurate and representative measurement of evapotranspiration rate. It is clear from his review that both the exposure as well as the moisture conditions in the soil of the lysimeter must be representative of those in the surrounding area if realistic values are to be obtained.

Bloeman (1964) also used a hydraulic weighing lysimeter and reported that in the measurement of evapotranspiration, precision can be increased with the use of precisely balanced hydraulic weighing lysimeters of bigger size.

The accuracy of evapotranspiration determinations by neutron

scattering method was evaluated by Bowman and King (1965). They found that for gravelly soils the probable error in evapotranspiration was less than 0.15 inch of water for a weekly period and less than 0.62 inch for a 3 month's period when one sampling site was used. Increasing the number of sampling sites decreased the error but not in direct proportion. The method was used to provide values for evapotranspiration from irrigated and unirrigated corn, wheat and clover in Ontario.

Dyer and Maher (1965) used an evapotron to measure evapotranspiration. The evapotron provides a measure of the vertical fluxes of the heat and water vapor.

Swinbank (1965) claimed that the automatic eddy-flux measurement with the evapotron is the most promising approach to the direct measurement of evapotranspiration.

Errors produced by the expansion or contraction of the zinc chloride solution used as a floatation medium in lysimeters are substantial and at times large enough to overcompensate deflection due to evapotranspiration. If these errors are not compensated for, the measurement device acts as a thermograph rather than a lysimeter. Insulating the stilling well and using double floats make it possible to reduce errors to only 3 percent of evapotranspiration (King, Mukammal and Turner, 1965).

The weighing lysimeters (as installed at Coshocton, Ohio; Davis, California; Madison, Wisconsin; and Guelph, Ontario) can yield a continuous trace of evapotranspiration. Such lysimeters are typically covered by crops indistinguishable from surroundings

(Thornthwaite and Hare, 1965).

Baier (1967) mentioned that lysimeters can provide useful data on evapotranspiration from a sample of soil and plants provided they are correctly designed, installed and maintained. It is essential to ensure that the lysimeter surface represents a fair sample of surrounding.

Dyer, Hicks and King (1967) designed a new version of evapotron and called it "fluxatron," because it was used only for the measurement of sensible heat transfer. They proposed an extension of the fluxatron technique to the measurement of water vapour transfer also.

Van Bavel and Stirk (1967) used a .150 mc. $Am.^{241}$ Be Source in otherwise standard neutron soil water content probe to measure evapotranspiration and claimed a precision of around 0.1 cm. of water.

Estimation of actual evapotranspiration

Butler and Prescott (1955) showed relationship between evapotranspiration, evaporation from open water, storage of water in the soil and rainfall in some Australian studies. On the basis of this relationship, they give an equation to calculate actual evapotranspiration, when evaporation from open water is known.

Pierce (1958) made an attempt to devise a rational procedure for estimating actual evapotranspiration from meadow crops using readily accessible meteorological data. He accomplished this by utilizing data from lysimeters at the U.S.D.A. soil and water conservation research station near Coshocton, Ohio. First a revised

curve for potential evapotranspiration was drawn and finally two corrections were developed by means of which allowance could be made for the level of soil dryness and the stage of crop development. He later (1960) described a method by which daily and other short period estimates of evapotranspiration from meadow crops could be made using mean temperature and rainfall. Starting with tentative determinations of potential evapotranspiration from mean temperature, four percentage correction factors are applied to accomplish needed downward adjustment for crop stage, dryness, length of day and occurrence of rainfall. Evapotranspiration losses are balanced against measured rainfall to yield daily estimates of crop moisture deficit, and hence currently available moisture.

The vertical energy balance yields reliable estimates of evapotranspiration on an hourly basis under large variations of thermal stratifications, provided the measurements are made close to a reasonably homogeneous surface and provided that suitable special and time-sampling procedures are followed. So claimed Tanner (1960) the energy balance method is relatively insensitive to incorrect assumptions concerning the eddy coefficients and to estimates of Bowen ratio (ratio of sensible to latent heat) except during the unusual, and most often uninteresting, conditions where evaporation approaches the sensible heat flux to the surface. The energy balance method, which measures the radiation exchange at the surface, places reasonable limits on evaporation estimates and thus is a promising method for daily estimates provided periods of positive and negative net radiation are considered separately or

that a reasonable estimate of the 24-hour Bowen ratio can be developed. In humid regions there is little transfer of sensible heat to the surface, so that when potential evapotranspiration conditions are obtained, the evapotranspiration will approximate the daily net radiation. In arid regions the evapotranspiration from a well-watered field may be, under extreme conditions, almost twice of the estimation made from the net radiation.

Rijtema (1961) stated that none of the evapotranspiration formulae is of much help in computing actual evapotranspiration during periods when water is in short supply.

Robins and Haise (1961) discussed many procedures for indirect estimation of consumptive use. They analysed the applicability, limitations, and type and quality of data available from the Blaney-Criddle, Thornthwaite, and Penman formulae and from atmometers and evaporation pans. The problems involved in determing evapotranspiration or consumptive use by irrigated crops are also discussed and their implications in use of data obtained for specific situations are analysed.

Blaney and Criddle (1962) gave the following formula for the computation of consumptive use (actual evapotranspiration):

$$U = KF$$

where U = use of the water in inches;

K = empirical seasonal coefficient; and

F = sum of monthly factors (f) for the season.

They asserted that the equation can also be used for monthly or short periods.

Jensen and Haise (1963) reported that the evapotranspiration in humid and semihumid areas can be predicted on a daily basis as well as for shorter time periods using an energy balance approach. In order to facilitate the application of energy balance concepts to semi-arid and arid areas, they collected the measured evapotranspiration data from irrigated areas in the Western United States, reevaluated and combined with estimates of solar radiation. Approximately 1,000 measurements of evapotranspiration for individual sampling periods for various crops were found usable. The results of this study provide mean numerical values to use in a dimensionless energy balance equation for predicting evapotranspiration. These data and procedure provide a simple technique for making evapotranspiration estimates in arid and semi-arid irrigated areas.

Lemon (1963) used the energy balance approach in estimating evapotranspiration and concluded that the net radiation and heat flux of the soil can be measured with sufficient accuracy.

By a combination of lysimeter technique and soil moisture control, Klausing (1965) obtained not only the data for the estimation of evapotranspiration, but, in addition, each measurement (soil moisture and evapotranspiration) enabled a check to be made on the other. The calculation of evapotranspiration was made on the basis of the water balance equation.

Makkink and Van Heemst (1965) worked out a calculation model, in which several processes are approximated quantitatively to arrive at the value of actual evapotranspiration of a crop period.

Thornthwaite and Hare (1965) discussed the physical approaches to the determination of evapotranspiration and concluded that all the means of estimating actual evapotranspiration are designed to serve the practical man and none can be claimed as wholly satisfactory, but several have considerable scientific merit.

The Blaney and Criddle method provides a fairly rapid procedure for transposing measured consumptive use data from one area to other areas for which only climatological data are available. The method has been used in most of the United States and has been found satisfactory for computing seasonal consumptive use where measured consumptive use data are not available (Blaney and Criddle, 1966).

Hargreaves (1966) gave the history of the development of evaporation and evapotranspiration formulae. He studied the ratios of evapotranspiration to Class A pan evaporation for a large number of crops and grouped the crops together into eight crop groups having similar consumptive use. Finally, he presented the formula for estimating consumptive use.

Mukammal, King and Cork, (1966) found that the aerodynamic methods gave evapotranspiration values close to the lysimeter measurements when the corn was short, but fell to only 40 percent of the measured values at the end of the season. They felt that the accuracy required in the various parameters in aerodynamic equations is greater than can be achieved or maintained with present instrumentation in the field. They recommended the use of the energy budget technique in computing evapotranspiration from tall crops.

The monthly and annual consumptive use estimates may be determined utilizing only the average monthly temperatures and a set of predetermined P.E. ratios. The method is called "P.E. Index Method." The results obtained by this method have been compared with those obtained by many other methods over a wide geographical range and a great divergence in cropping procedures as well as different crops. It should be stressed that any empirical formula will produce better results in the hands or the originator than it will in strange hands (Munson, 1966).

Shanon (1966) used the correlation between measured actual evapotranspiration and evaporation from black and white atmometers. He used this correlation and developed an equation for estimating actual evapotranspiration from crops.

Soil Studies

Infiltration

Factors affecting infiltration

Of the various factors which may modify the rate of infiltration of water into field soils, the percentage porosity is one of the most important. Increasing the average percentage of pore space through surface cultivation markedly increases the rate of infiltration. Although the infiltration rate may be greatly modified by changes in porosity resulting from soil moisture changes or varying vegetative cover, yet the dominant factor may well be soil type (Musgrave and Free, 1936).

Duley (1939) concluded that the thin compact layer which forms on the surface of bare soils during rain has a greater effect on the

intake of water than has the soil type, slope, moisture content or profile characteristics.

Horton (1940) mentioned that the total infiltration from a shower of given size is influenced by the absorptive and storage capacities of the surface layers and the rates of percolation.

Musgrave (1955) summarized the major factors that affect the intake of water by the soils as follows: (1) Surface conditions and the amount of protection against the impact of rain, (2) Internal characteristics of the soil mass, including pore size, depth or thickness of the permeable portion, degree of swelling of the clay and colloids, content of organic matter, and degree of aggregation, (3) Soil moisture content and degree of saturation, (4) Duration of rainfall or application of water, and (5) Season of the year and temperature of soil and water.

Hall (1956) reported that as the surface layers become saturated, the rate of infiltration decreases rapidly due to the compacting action of rain drops, 'washing in' of the fine colloids and swelling of clay particles in the surface layers, to the increasing resistance to flow as the wetting front extends to a greater depth, and to the decrease in pore size within this path following swelling of solid particles.

The rate of infiltration will be determined by the permeability of successive layers; thus a layer of low permeability may often determine the rate of flow through a considerable depth of soil. The permeability of surface layers often influences the infiltration rates of arid soils to a marked extent. Many soils are covered by a thin film of readily dispersible clay colloids, either naturally or following the removal of the top few centimeters

by wind erosion. On wetting, this material swells and forms an almost impervious barrier to the entry of water (Condon and Stannard, 1957).

Logan (1957) reported that high salinity conditions result in extremely low permeability and infiltration rates in soils of New South Wales.

Philip (1957) found that shortly after infiltration begins, increasing the moisture content reduces the infiltration rate. As the time increases the influence of initial soil moisture on infiltration rate becomes less and is ultimately negligible.

Zingg and Whitfield (1957) concluded that the rate of infiltration is influenced by the moisture content of the soil at the beginning of the shower, being greatest in dry soils.

Bertrand, Barnett and Rogers (1964) made correlation and regression analyses to identify the factors significantly affecting infiltration rate and found soil texture, organic matter content and initial moisture content were the most important factors.

Fernandez and Wilkinson (1965) reported that the aggregate stability had its largest influence on infiltration after the first 30 minutes of water application. The amount of water absorbed during all periods of infiltration was influenced by initial moisture content. The influence was greatest during the first 30 minutes.

Khybri (1965) reported from his studies on the soils of Nepal that the infiltration rates vary from moderately slow to moderately rapid rates depending upon soil types and site conditions.

He observed higher infiltration rates with soils having high organic matter content, friable consistency and crumb structure.

Studies by Mistry and Chatterjee (1965) showed that the rates of water infiltration were highest in light textured forest soils high in organic matter (26 cm./hr.) and lowest in gullied uplands (4 cm./hr.); they were greater in soils under permanent woodland and pasture vegetation (14.5 cm./hr.) than in those under arable crops (5.8 cm./hr.).

Watson (1965) analysed statistically the relative importance of such factors as initial moisture content, simulated rainfall intensity and sub-surface cracking on the infiltration capacity and concluded that it is not possible to separate these effects although it is considered that the presence of the macro-cracks is the dominant contributor.

Mannering, Meyer and Johnson (1966) found that as compared to conventional cultivation with plough, harrow and disk, minimum tillage increased infiltration by an average of 24 percent on sloping silt loam during a five-year period. They explained this by asserting that the minimum tillage slightly improved soil aggregation, porosity and organic matter content.

Bisal (1967) determined the infiltration rate with respect to rainfall energy on a clay, a loam and a sandy laom. With an application of 2.0 cm. of simulated rain, the infiltration rate of the saturated clay fell from 2.4 to 0.6 cm. per hour, of the loam from 4.0 to 0.6 cm. per hour and of the sandy loam from 14.5 to 9.5 cm. per hour. Raindrop energy was from a 4.6 mm. diameter

drop falling through a 6.55 m. height. He concluded that to maintain a high level of infiltration, surface soil must be protected from rainfall energy.

Haupt (1967) reported that on a 15 percent slope on cobbly sandy loam derived from andesite, a rapidly melting snow-pack over soil containing dense frost may accelerate on-site runoff. Stalacite soil frost promoted rapid absorption of snowmelt and reduced overland flow. Porous concrete frost usually reduced infiltration capacity and increased overland flow on burned or sparsely vegetated sites but did not impair infiltration where plant and litter cover were appreciable. Generally, plants, litter and snow cover dissipated raindrop energy and increased infiltration. Shallow contour furrowing seemed to facilitate infiltration.

Powell and Beasley (1967) concluded that the effect of erosion on infiltration in various silt loam soils depended particularly on surface characteristics of the soil. Infiltration decreased most (up to 60 percent) when the soil was cropped and the density of the surface soil was high. Intial moisture had greatest effect on infiltration rate with bare well tilled soil, but the final infiltration rate was little affected by it. Bulk density and aggregation, which change throughout the year with tillage, can greatly affect infiltration rate.

Measurement of infiltration

Parr and Bertrand (1960) in their review on "water infiltration into soils" pointed out the great diversity of methods used

in measuring infiltration. They claimed that no one method yet developed meets all needs.

The following methods have been used by various workers in different parts of the world:

(a) Artificial rainfall method

Adams, Kirkham and Nielson (1957) described a portable rainfall simulator and infiltration cylinder. In their apparatus, the artificial raindrops are formed at the bottom of glass capillary tubes protruding through the base of the water supply tank. A variety of drop sizes may be produced by varying the size of the capillary tube and the diameter of the wire inserted in each tube. The rate of artificial rain is controlled by the head of water in the supply tank.

An infiltrometer using a drip tower was developed by Barness and Costal (1957). In their apparatus, artificial rainfall ranging in intensity from 1 to 6 inches per hour is provided by selected nozzles that spray on a drip screen with yarn thread. The area around the 12 x 18 inch plot receives simulated rainfall in equal intensity and hence provides a buffer area. Runoff is collected at the downhill end of the plot by a suction apparatus that deposits the water in a Friez recording rain gauge. A calibration of rainfall intensity is obtained by placing a collecting pan over the plot for a known length of time before and after the run.

Meyer and McCune (1958) used the movable-carriage principal in the design of a rainfall simulator. The Veejet nozzle used in this apparatus produces artificial rainfall in which the size

distribution, velocity and energy of the drops are similar to those of raindrops in natural storms.

Bertrand and Parr (1961) designed a portable sprinkling-type infiltrometer. This instrument employs a single full-cone nozzle, spraying downward from a height of 9 feet. The plot is 3.81 feet square and bounded by a metal frame driven two inches into the soil. The downhill side of the frame is slotted to allow runoff water to leave the plot and enter a special flume. The drop size, the drop distribution, and kinetic energy of artificial rainfall produced by this apparatus compare favourably with values for natural rainfall.

(b) Flooding methods

Marshall and Stirk (1950) recommended the use of cylinder type infiltrometers for the measurement of infiltration rates. They pointed out that where the cylinders are not driven into the soil to a considerable depth, and where the diameter is small enough to be convenient for experimental use, the rate of water intake per unit area varies markedly with the size of the cylinder, decreasing asymptotically with increasing diameter of the cylinder.

Daniel (1952) used an infiltrometer consisting of two concentric rings, two carburetor floats, a 10-gallon oil drum, and a recording rain gauge. The inner ring was made 8 inches in diameter in order to correspond with the calibration of the rain gauge. Water for the outer ring was supplied by gravity from the drum. The water level in the two rings was maintained uniform and constant by

carburetor floats.

Bondurant (1957) developed the furrow infiltrometer to stimulate closely the infiltration conditions existing in a furrow during irrigation. This infiltrometer provides a means of measuring furrow infiltration rates when field measurements are not feasible.

Burgy and Luthin (1957) found with the use of single rings on an extremely uniform soil, that each of six separate measurements came within 30 percent of the general mean.

Slater (1957) used sprinkling and water impoundment in a small cylinder infiltrometer to determine the infiltration rates on cultivated soils. Sprinkling procedures with a type F.A. infiltrometer and manually controlled sprinkling were used in a manner that provided rate measurements. The cylinder infiltrometers were "single-ring" type.

Swartzendruber and Olson (1961b) studied the double-ring infiltration technique using a sand model with dyes in the water found that the infiltration velocity increased sharply as the wall of the outer cylinder was approached. Under otherwise equal conditions, the rate of water intake at the center of the rings was found to increase if the diameter of the inner ring was reduced to 12 inches or less. In further studies involving uniform material, restricting layers, impermeable layers, different textures, and different depths of wetting, they found that rather successful results were obtained with an inner cylinder 40 inches in diameter and an outer cylinder 48 inches in diameter.

Bertrand (1965) reported that the disturbance of the soil incident to placing cylinder infiltrometers in position for measurement may have a significant effect on the results obtained. Some shattering or compaction of soil adjacent to the border is inevitable when cylinders are driven into position.

Khybri (1965) developed an automatic device for maintaining the constant head of water for infiltration studies and found it satisfactory under different soil and site conditions. An air inlet tube, adjusted between angles 65 degrees and 75 degrees with the horizontal, was found convenient for maintaining the constant head. The double ring infiltrometer was used.

Runoff

Baver (1956) stated that the influence of length of slope on runoff appears to vary with the soil permeability and intensity of rainfall, there being less runoff with increase in length of slope on highly permeable soils and with showers of low intensity whereas the reverse holds on impermeable soils with showers of high intensity.

Logan (1957) found that in salt affected soils, extremely low permeability results in surface ponding. Depending on the degree of slope, there may be a considerable runoff despite a low annual rainfall.

Gard, Jacob and Van Doren (1959) in Illinois found that the soil treatment reduced runoff during each of four seasonal periods. Runoff was higher from severely grazed than moderately grazed plots during the grazing season (April through September) but not during

the non-grazing season (October through March). As the seasons progress from January through September more intense storms are required to cause equal runoff. Also, they reported that percent runoff generally increased with increases in initial moisture. Values obtained for the regression of runoff on amount of rainfall indicate that there are too many variables for ratios to be useful.

Grant and Struchtemeyer (1959) studied the influence of coarse material on infiltration and runoff in Maine potato soils. They found a significant decrease in the rate of infiltration and likewise an increase in runoff as particles larger than 12.7 mm. were removed from the soil.

Runoff, although largely determined by soil, climatic, vegetative, and topographic factors, is also affected by management practices. Russell (1959) discussed some of these. Maintaining a high infiltration rate for a long period is a key objective for the control of runoff and erosion. This is achieved by practices that increase the supply of readily decomposable organic matter, provide a protective canopy over the soil surface, and reduce the number of tillage operations, particularly during periods of high soil moisture. Grazing practices on range land and forest-management practices in timbered areas, have important effects on the runoff intensities of watersheds.

Tamhane _et al._ (1959) studied the correlation between runoff and rainfall intensity and reported a curvilinear relationship with highly significant and positive correlation between runoff and the intensity of erosive rainfall.

Thames and Ursic (1959) reported that the soil moisture, rainfall and surface-runoff records from a small watershed in northern Mississippi show surface runoff to be strongly correlated with storage apportunity in the top six inches of the soil. They developed a logarithmic expression to describe surface runoff from individual storms as a function of amount of rainfall and initial available storage.

Ursic and Thames (1959) found that surface runoff and peak flows were greatest from abandoned fields, intermediate from depleted uplands and least from 20-year old loblolly pine plantations on eroding farmland. Also, the runoff increased with proportion of loessial soil. The presence of a shallow, slowly permeable fragipan more than doubled the amount of surface runoff.

Haylett (1960) found the greatest runoff occurring from bare plots, less when row crops were growing, and still less with close growing hay crops. These losses were reduced to negligible amounts by a cover of perenial pasture or natural veld. The total amount of runoff was not materially influenced by the slope.

Krammes and Hellmers (1963) concluded that the spraying of a soil-binding chemical solution formed a thin crust, increasing the runoff on the ash-dust layer and bare surface of steep, burned slopes. Application of a detergent to water to decrease its surface tension promoted infiltration and decreased runoff.

Schumm and Lusby (1963) reported that the raindrop impact during the spring and summer in western Colorado compacted the lithosol derived from weathered shale, decreasing the infiltration

and increasing the runoff. The average runoff and ratio of runoff to precipitation were less in the spring than in the autumn, reflecting the seasonal changes in soil properties and their effect on the hydrological characteristics of small drainage basins.

Hamon (1964) stressed that the runoff for small watersheds can be calculated from storm rainfall, initial soil moisture, and the amount of water retained before the start of runoff by means of an equation, including all these factors.

Taylor et al. (1964) found that a mulch of corn stover and barnyard manure gave excellent control of water losses from corn after corn on a steeply sloping deep loess soil. During nine years of measurement in Wisconsin, losses of soil and water from corn after corn with a mulch were less than corn or oats without mulch in a corn-oats-hay rotation and were about equal to the losses from the meadow in the rotation.

DuPlessis (1965) measured runoff for 13-18 years on 9 x 100-foot plots on a red sandy-loam soil with a 5 percent slope. Runoff was highest of course from bare plots. Runoff from unfertilized maize was about the same as that from cultivated bare soil. Runoff from well fertilized maize monoculture differed little from that from maize grown in rotation. In veld management plots much runoff occurred where veld was burned and grazed; it was nearly as great as runoff from bare fallow plots and three times as great as runoff from veld moderately grazed but not burned. The runoff from protected veld was lower than from other plots; the runoff was less than 3 percent of the annual rainfall.

Gardner (1965) discussed spring runoff. Runoff from snow is usually related to amount of precipitation during the winter, rather than to a single storm. The amount of precipitation absorbed by the soil depends, in this case also, upon the initial moisture content of the soil. It also depends upon whether and how long the soil is frozen. The exact time of the runoff is less predictable since this is a function of the melting of the snow, which depends upon weather that is difficult to forecast. However, the amount of runoff from snow under certain conditions can be predicted by means of snow surveys.

Wischmeier (1966) analyzed the data from nearly all erosion plot studies in the United States and concluded that the averages of runoff from cropped plots are 3 to 36 percent of the total precipitation. Improved soil and crop management reduced average plot runoff about 40 percent. At moderate fertility levels, runoff reduction by contour tillage averaged slightly more than a 15 percent reduction. Runoff was inversely proportional to organic matter but was little affected by texture of the soils.

Measurements of runoff by Jamison and Peters (1967) after prolonged irrigation of grass plots on a clay pan soil showed that recession yields of runoff per unit area increased with slope length. Yields from slopes of lengths varying from 76 to 323 feet indicated return flow during runoff recession of at least 0.1 inch from the longer plot.

Wischmeier (1959) concluded from analysis of extensive data from research projects in 21 states that the maximum 30 minute

intensities of rainfall were more closely correlated with run off and soil loss than the rainfall intensities for other durations. Wischmeier's conclusion may not necessarily be valid for Alberta, where the records available show that the periods of intense rainfall are invariably of much shorter duration. A study of the records for individual storms by Toogood (1963) shows that the intense periods of rainfall are of short duration. He conjectured that the correlation between soil losses and rainfall intensity might be higher in Alberta for 15-minute intensities than for 30 minute intensities.

Available water capacity of soils

Definition

"Available water" refers, for a soil sample, to the water content difference between field capacity and wilting point; for a field soil, it refers to the total available volume of water per unit area of soil (Richards, 1956).

Tames (1961) stated that the water retained by soils between pF 2.7 and pF 4.2 is available to plants. The capillary movement of the water retained over pF 2.7 is too slow to compensate for the losses caused by evapotranspiration during the period of active vegetation. Consequently the plant roots must reach the water in order to take that part which is retained within the pressure range of pF 2.7 and pF 4.7. Therefore, water lying beyond the reach of the root-system may be considered nonusable water at pF values greater than 2.7.

Peters (1965) defined the available water capacity of soils as "the amount of water that can be used or removed from soil in support of life of higher plants". The available water content is the difference between the water content at field capacity and the water content at the permanent wilting point.

<u>Factors affecting available water capacity</u>

The moisture holding capacity in irrigated soils was found by Wilcox (1939) to be affected by the following factors: (a) Texture of soil. There was a high positive correlation with percentage silt plus clay. (b) Time after irrigation. The heavier soils drained more slowly. (c) Depth of sampling. Some variability was found in moisture retention as affected by the depth. (d) Type of subsoil drainage.

Wilcox and Spilsbury (1941) found that as the colloid content of the soil increased, the wilting coefficient at first increased less rapidly than the field capacity, with a resulting increase in the available moisture. Above 60 percent colloids, they increased at about the same rate, resulting in a levelling off of the available water capacity.

The moisture holding capacity of a soil depends on the depth of the soil layer considered, and the type and structure of the soil. It can vary from just a few millimeters on a shallow sand to well over 400 mm. on a deep well-aerated silt loam. The roots of plants compensate somewhat for the variable nature of soil, for on sandy soils plants will be deep-rooted while on silts and clay the

plants tend to be more shallow-rooted. Thornthwaite and Mather (1955) give a general discussion on this subject.

Jamison (1956) reported that the available moisture storage capacity is usually reduced by structural changes that decrease bulk density, including the effect of organic matter increases (except for sandy soils). The storage capacity of a soil that has remained in an undisturbed state for some time is usually increased by tillage if the soil is repacked to about the same bulk density.

Jamison and Kroth (1958) reported that the analysis of the available moisture storage data for 271 profile horizon samples from Missouri show that, for these dominantly silty soils, available moisture storage capacity decreases with clay and increases with silt content. Coarse silt (0.05 to 0.02 mm.) increases available water capacity more than fine silt (0.02 to 0.002 mm.). Available water capacity also increases generally with the organic matter content but since organic matter increases with coarse silt and decreases with clay, the effect can be attributed to textural changes.

Bartelli and Peters (1959) concluded that the available soil moisture and field capacity vary according to textural class for each soil group they studied. Also, as in Jamison and Kroth's study reported above, they found the available soil moisture was controlled principally by the silt fraction. Lund (1959) also concluded that alluvial soils in Louisiana have a high available-water holding capacity mainly due to their high silt content.

Salter and Williams (1963) reported that annual applica-

tions of farmyard manure for 7 or 8 years led to a significant increase in the available water capacity of a sandy loam soil and in the volume of water released at low tensions. The available water capacity increased, and the moisture characteristics altered, as the soil became more compacted during crop growth.

Sonmez (1964) measured the permanent wilting point percentage of 25 soils and found that it increases with the clay content and decreases with increasing sand fraction. There was a similar trend in relationship between field capacity or available soil moisture and soil texture.

Salter and Williams (1965b) concluded that the moisture content at field capacity and at permanent wilting point increased as the soils became finer in texture but the medium textured soils held the greatest volume of available water.

Ali, Chaterjee and Biswas (1966) reported in their work on Indian soils that on the average, the available soil moisture is high in black, mountain and forest soils and low in laterite soils. In all the soil groups, moisture retention was mainly a function of organic matter.

Lutz _et al_. (1966) in their laboratory studies found that phosphate application appreciably increased the water-holding capacity of soils. This was found to be directly related to the increase in the negative charge of soil particles and the charge was closely related to the Al-phosphate/Fe-phosphate ratio. In general, increases in water holding capacity were caused only by larger rates of phosphate fertilizer (up to 1600 ppm P), but in

some instances to 50 ppm P gave significant increases.

Salter, Berry and Williams (1966) found the available water capacity negatively correlated with percentage of coarse sand and positively correlated with percent of international fine sand and organic carbon.

Hill and Sumner (1967) illustrated the effects of bulk density on available water capacity of soils. In most soils, in the plant available moisture range, moderate compaction results in an increase in moisture content at constant matric suction.

Estimation of available water capacity

The soil moisture contents at the upper and lower limits of available water are required in order to determine the available water capacity of a soil.

(a) Upper limit of available water

Field capacity is normally regarded as the upper limit of available water. Veihmeyer and Hendrickson (1931) defined field capacity as "the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased". In a later publication (1949) they reported the moisture equivalent as a measure of field capacity or upper limit of available water and suggested 1/3 atmosphere suction as a rapid and reliable measure of field capacity.

Colman (1947) found that small soil blocks under a suction of 1/3 atmosphere retained an amount of moisture related empirically

to the field capacity of the same soils determined under field conditions. He gives also, the details of apparatus and procedure used.

Haise, Haas and Jensen (1955) found field capacity correlated with 1/3 atmosphere percentage. Also, they reported that a comparison of 1/10- and 1/3-atmosphere retention values, determined on undistrubed soil cores, indicated that the moisture content at field capacity corresponded more closely to the 1/10- than to the 1/3-atmosphere percentage.

The United States Bureau of Reclamation (1948) found that for the sandy soil occuring on the Yuma Mesa, Arizona, the water retained in a sample of soil at the 1/10-atmosphere percentage satisfactorily approximates the upper limit at available water under field conditions.

Salter and Haworth (1961) compared the results of determining the moisture content at field capacity and found that the direct method involving soil sampling after irrigation and when drainage had almost ceased, gave more accurate and consistent results than the suction-plate method using any single tension.

Salter and Williams (1965a) compared the direct method and 1/3-atmosphere percentage method of determining the upper limit of available water. They concluded that 1/3-atmosphere percentage is very appropriate, if done on undisturbed samples.

Rickard and Cossens (1967) concluded that neither the 1/3-bar retention value nor the moisture equivalent is a reliable value or estimate of top soil field capacity, which can only be

determined reliably in the field in their opinion.

(b) Lower limit of available water

Permanent wilting percentage has been accepted as the lower limit of available water.

Permanent wilting percentage values determined on a group of soils from western United States were compared by Richards and Weaver (1943) with the 15-atmosphere percentage values. For these soils the 15-atmosphere percentage formed a fairly definite lower limit below which the permanent wilting percentage seldom falls.

Furr and Reeve (1945) first elucidated the concept of permanent wilting point and gave a detailed procedure for the determination of permanent wilting point percentage by using dwarf sunflower (Helianthus annus). Later on Veihmeyer and Hendrickson (1949) also used this procedure with a slight modification.

Veihmeyer and Hendrickson (1949) also suggested the 15-atmosphere percentage as an indication of permanent wilting percentage values. However, they stated that the values were more reliable when determined by sunflowers grown on undisturbed soils.

Haise, Haas and Jensen (1955) reported that the wilting point percent was correlated with the 15-atmosphere moisture percent.

Richards (1956) indicated that the 15-bar percentage, because of its close correspondence to the wilting point, appears to be an index of the lower limit of available water in the soil.

Lehane and Staple (1960) related permanent wilting

percentages based on the wilting of the upper leaves of sunflower plants to the 15-atmosphere percentages by the equation PWP = 0.35 + 0.833 FAP. This wilting percentage, which was lower than that based on a mean wilting condition of the plant as a whole, provided satisfactory estimates of minimum soil moisture contents under cereal crops at harvest time.

Wilcox (1960) reported that the 15-atmosphere percent is not synonomous with wilting point. He says that the safest procedure found was to use the regression line between the two. He gave the following equation:

$$WP = -0.662 + 1.016 \times FAP$$

Salter and Haworth (1961) reported that the permanent wilting percentage determined on undisturbed cores and on crushed samples of soil by the sunflower technique showed significant differences and for critical work the results of determination made on soil cores were preferred. The desiccator method of determining permanent wilting percentage was found to be insufficiently accurate for use in this type of work.

Salter and Williams (1965a) used the 15-atmosphere percentage as the lower limit of available water and found it high as compared with the permanent wilting percentage determined on undisturbed soil cores.

Salter and Williams (1967) reported a direct method of estimating available water capacity of soils in the field. The procedure is as follows:

(a) measure the thickness of each horizon,

(b) assess its texture,

(c) sum up the products of the thickness of each horizon and the mean values of available water capacity for the relevant textural classes.

Soil Moisture Availability to Plants

Veihmeyer and Hendrickson (1950) reviewed the relevant papers in this subject. They concluded that the increase in energy required to transpire water, from field capacity to permanent wilting percentage, is unimportant when the system as a whole is considered.

Later on Veihmeyer (1956) from an extensive literature review confirmed his original belief that "permanent wilting does not occur at moisture contents higher than permanent wilting percentage under conditions of evaporation likely to be met with in the field."

Stanhill (1957) also reviewed the literature relevant to availability of soil moisture to plants and reported that in over 80 percent of the experiments growth was affected by differences in the amount of available water depleted before the soil was rewetted.

Gardner (1960) reported that as a soil dries out, the suction of the soil water increases; thus the suction in the plant root in contact with the soil water must increase in order to maintain the uptake of water from the soil. If water at a distance from the root is available, it will move towards the plant root in response to the suction difference. If the water uptake proceeds at a rate greater than the replenishment, the point will be

reached at which soil suction equals plant suction and evapotranspiration ceases. In 1962 he reported than when soil suction is low, the rate of transpiration is dependent only on the evaporative conditions and is equal to potential evapotranspiration. As the soil dries, the soil suction increases most rapidly in the region of greatest water use which is in the shallower depths of the soil because of the greater root concentration. The water content of the plant is reduced with the result that the suction in the plant leaves increases sufficiently to maintain the rate of water uptake equal to the rate of loss. This in turn results in the greater uptake of the water from the soil regions with a lower concentration of roots. Eventually, a point is reached where the soil suction exceeds the suction in the plant leaves and actual evapotranspiration becomes a function of the moisture content of the soil and potential evapotranspiration.

It is accepted that soil moisture is available to plants for transpiration over the range from field capacity (1/3 atm. or pF = 2.7) to permanent wilting percentage (15 atm. or pF = 4.2). Contradictory view points can be summarized as below:

1. <u>The soil moisture is equally available between field capacity and permanent wilting point percentage</u>.

This concept was put forward by Veihmeyer and Hendrickson (1950) and later on was supported by Veihmeyer and Hendrickson (1955) and Veihmeyer (1956). They concluded that the water is equally available for transpiration by plants almost throughout the range from field capacity to permanent wilting point percentage.

Van Bavel (1955) and Lowry (1959) also supported this concept.

Penman (1963) contradicted this concept stating that this may be true in certain situations for some plants, but it is doubtful for many other plants and environmental conditions.

2. No substantial reduction in actual evapotranspiration except in very dry soil.

Pierce (1958) suggested this concept on the basis of his experiment on fully rooted meadow crops grown in lysimeters. He reports that the actual evapotranspiration rate was maintained at 90 percent of the potential rate until about two-thirds of available moisture had been exhausted from the top 30-36 inches of soil.

Gardner (1960) supported this concept by obtaining similar results for a sandy soil and for a low leaf osmotic pressure.

Denmead and Shaw (1962) also arrived at similar conclusions with corn plants grown in containers in silty clay loam soil.

3. Composite drying curve.

Penman (1949, 1956 and 1963) considered the soil and plant as one system as far as availability of water is concerned. The depth of root zone and available water in it, "the root reservoir of water", depends on the crop rooting characteristics, type of soil, crop management and soil moisture distribution in the early part of the growing season. The amount of water within the root zone plus one inch of water extracted from the soil below the roots is available for transpiration at the potential rate. The relationship as described takes into account various root constants and is expressed by a so-called composite drying curve for

saturated and non-saturated conditions. Holmes and Robertson (1963) incorporated this approach in soil moisture procedures.

4. Linear availability of soil moisture between field capacity and permanent wilting point percentage.

Thornthwaite and Mather (1954, 1955) assumed that the water availability is proportional to the amount of water remaining in the soil.

Smith (1959) found that the Thornthwaite concept is most suitable for field conditions under shallow-rooted Savanna grass.

Gardner and Ehling (1963) also supported this concept and indicated that the evapotranspiration from pepper and trefoil plants grown in shallow containers was almost linear over the range from field capacity to permanent wilting point percentage.

James and Brumbach (1966) used this relationship in estimating available soil moisture for the crops in the Connecticut area.

5. Exponential decay form relationship.

Lemon (1956) suggested this concept. He assumes three stages of moisture loss over the availability range. In the first stage, the moisture rate proceeds at the potential rate as long as the moisture is available at the plant's roots or at the soil surface in the case of bare soil. In the second stage, when the soil begins to dry and moisture is not conducted to the interface fast enough to meet the atmospheric demand, the relative evapotranspiration declines rapidly as the moisture content decreases. The drying curves are exponential in general shape. In the third stage, the moisture loss by vapour diffusion is very slow and takes part only

from the dry surface layers of the soil. The range of available moisture over which the three stages occur is dependent on moisture characteristics of the soils and rooting characteristics of the crops.

Denmead and Shaw (1962) supported this concept and produced similar curves from their experiments.

Summary

1. A moisture balance study includes a careful estimation or measurement of several variables, namely, precipitation, infiltration, runoff, deep percolation, soil moisture storage change, and evapotranspiration. Moisture balance patterns have been studied in various parts of the world, however, for western Canada the only studies have been those by Dr. A. H. Laycock, 1967. He mapped the defiency pattern using Thornthwaite, Lowry-Johnson and Blaney-Criddle procedures for estimation of potential evapotranspiration. Because of lack of data on available water capacity for the soils in the area, he made his estimations of moisture deficiency on the basis of various assumed values of available water capacity of soils.

2. Potential evapotranspiration is an estimate of moisture loss from any area, under complete cover of actively growing vegetation, flourishing under optimum moisture conditions. Among various methods of estimating potential evapotranspiration, Penman's procedure seems to be the most appropriate since it has combined aerodynamic and an energy balance approach in the estimation.

3. Actual evapotranspiration is the amount of soil moisture, evaporated from the ground or transpired by the plants. When moisture content in the field falls below field capacity, the actual evapotranspiration is controlled by soil moisture release properties in addition to meteorological and vegetation factors. Baier and Robertson (1966) in Ottawa, have suggested the most recent method, as far as Canada is concerned, for estimation of actual evapotranspiration. In their method the use of soil drying curves and division of available moisture into several zones is quite empirical and requires specific data on individual soils.

4. Infiltration is the intake of water into the soil. When it is compared with intensity and duration of precipitation and soil permeability, it gives an estimation of runoff. The infiltration rate is determined mainly by soil properties such as texture, structure, organic matter content, presence of hard pans or impermeable horizons, and the initial moisture content of the profile. Only meagre data on infiltration rates in the soils of Alberta have been available up to the present time.

5. Available water is the amount of water held between field capacity and permanent wilting point. The 1/3 to 1/10-atmosphere percentages have been used as an index of the upper limit (field capacity) and the 15-atmosphere percentage as an index of the lower limit (wilting point percentage) of available water in the soils. There are no data published on the available water capacity of the soils of the Edmonton area.

6. The relationship between amount of available water and rate of

evapotranspiration is not yet resolved. The question is whether evapotranspiration decreases steadily in a straight-line relationship as the available soil moisture decreases below field capacity or, on the other hand is the relationship curvilinear, with little decrease in evapotranspiration under soil moisture is seriously depleted and then a very rapid decrease.

MATERIALS AND METHODS

Description of the Area Used in the Study

Location

The Edmonton map sheet 83-H is located in central Alberta, and comprises an area approximately 80 miles east and west by 70 miles north and south. The area lies between 53 and 54 north latitude and 112 and 114 west longitude. It consists roughly of townships 47 to 57 inclusive from the west half of range 14, west of the 4th meridian, west to the 5th meridian (Fig. 1). The whole area covers 149 townships, or parts thereof, amounting to approximately 3,600,000 acres (Bowser *et al.*, 1962). This reference is also the source used for information below on climate, topography, parent material and soils.

Climate

The climate of the Edmonton Sheet area is continental, characterized by relatively warm summers and cold winters. The mean summer temperature, May to September inclusive is 55°F. July is the warmest month, averaging 61.5°F. The mean winter temperature, November to March inclusive is 16°F. January is the coldest month. The average frost-free period is about 100 days with an extreme variation from about 50 to 150 days.

The mean annual precipitation is from 16 to 18 inches--increasing from east to west in the area. June, July and August are the months of highest rainfall, totalling an average of just over 9 inches. Laycock (1967) reported that the area has a moisture

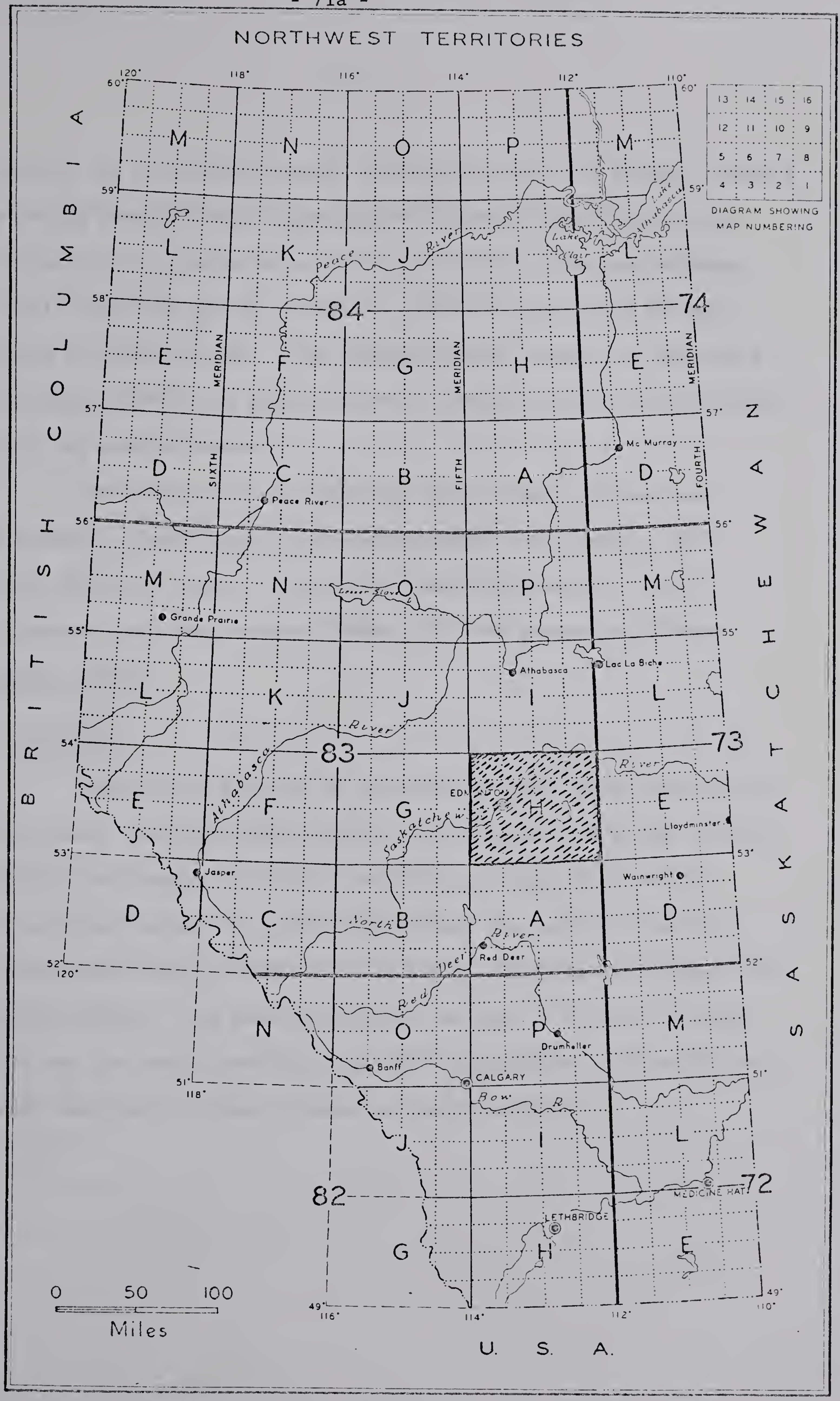

Fig. 1. Location of the Study Area.

deficit for the growing season, varying from 2 to 8.5 inches, assuming a 4-inch available water capacity of the soils. Approximately 70 percent of the precipitation falls as rain and 30 percent as snow, usually when the ground is frozen. The area has, on the average, about 50 inches of snow. The rainfall during summmer, as described by Toogood (1963), is generally low in intensity and well distributed over the growing season.

The area can be considered as being between dry and moist sub-humid. There is no pronounced permanent water table. Soil-wise there is a zone of salt and of lime accumulation: these represent the average depth to which the rain penetrates (Bowser et al., 1962).

Topography

Roughly the area can be divided into three main topographical divisions. The east third—that is, the area east of a line through Tofield and Lamont--is level to undulating, having many shallow depressional areas. The centre third that lies south of the North Saskatchewan River is undulating to hilly, primarily of the knob and kettle variety. The western third of the area is level to rolling. The area has been classified into four topographical classes and the area under each of these classes is listed in Table 1.

TABLE I

Topographical Classification of the Edmonton Sheet Area

Class	Acreage	% of Area
Level and undulating	2,631,000	72
Gently rolling (5 to 9 percent slopes)	423,000	11.6
Rolling (10 to 15 percent slopes)	294,000	8.1
Hilly (over 15 percent slopes)	14,000	0.4
Other areas:		
Rough broken land	34,000	0.9
Water	254,000	7.0
Total:	3,650,000	100.0

Parent Material

The area is underlain by Paskapoo formation in the southwest corner, and then by Edmonton, Bearpaw, Pale beds, Birch Lake and Grizzly Bear, as we move from southwest to northeast. Paskapoo formation, consisting of sandstones and soft shales, is of fresh water origin and is quite calcareous. Edmonton, a brackish water formation, consists of bentonitic sandstones, sandy shales, bentonitic clays and coal seams. Bearpaw and Grizzly Bear are marine formations. Birch Lake, Pale Beds are also fresh and brackish water formations, and the latter has ironstone modules and gypsum crystals mixed with shales.

Bowser *et al.*, reported the following types of parent material in the Edmonton Sheet.

TABLE II

Area Under Various Deposits in the Edmonton Sheet

Parent material	Acreage	% of Area
Till	1,798,000	49.2
Lacustrine	548,000	15.0
Alluvial lacustrine	334,000	9.2
Alluvial aeolian	258,000	7.1
Aeolian	34,000	0.9
Residual	145,000	4.0
Pitted Deltaic	75,000	2.1
Alluvium	16,000	0.4
Water	254,000	7.0
Outwash	10,000	0.3
Organic	109,000	3.0
Erosion	34,000	0.9
Miscellaneous	35,000	0.9
Total:	3,650,000	100.0

Vegetation

The native vegetative cover changes in gradual pattern from east to west--from open parkland to continuous forest. The grass vegetation is the dominant cover in parkland area. Moss (1955) described this grass cover as the rough festuca (*Festuca scabrella*) association. He suggested also that the groves of aspen poplar, scattered in the area, were established possibly in comparatively recent times.

The poplar association in the Cooking Lake and the northwest portion of the area, as described by Moss (1955), may be divided into two consociations--the aspen consociation and the balsam consociation. The vegetative cover in the area consists of many other plants also. There are literally hundreds of species of plants, including shrubs, herbs, grasses, mosses and lichens.

Soils

The soils selected for this study were classified and mapped by Bowser et al., (1962). The classification system is in accordance with the National Soil Survey Committee of Canada (1960).

The area consists of 1,808,000 acres of Chernozemic; 905,000 acres of Solonetzic; 379,000 acres of Pidzolic; 69,000 acres of Regosolic; and 54,000 acres of Gleysolic soils. The east third of the area from south to north is dominated by Solonetzic soils. The Podzolic soils occur in the moraine around Cooking Lake and along the western edge of the area. The remainder is Chernozemic soil having the Gleysolic soils in the poorly drained area.

Sampling

Selection of the Sites

Twenty-two different soil types were selected to study the moisture balance in soils of the Edmonton area. The main consideration in selecting the soil series was the total acreage of the soil type in the area. The area occupied by these selected soil types is 2,835,000 acres, or about 88 percent of the total soil

acreage of the area.

Representative sites of each soil type were selected. More than one site was chosen for certain selected soil types, namely, Ponoka Loam, Malmo Silty Clay Loam, and Angus Ridge Loam, not only because of their larger acreage in the area, but also, to study the variation in available water capacity in different areas of the same soil type. See Figure 2 for location of sampling sites.

Collection of Samples

The soil sampling was done in the summer of 1965. The Bull Core Sampler was used for sampling at most of the sites. A few sites which are very coarse-textured, had to be sampled with tin cans. Each of the sites was sampled down to four feet in five replicates. Each soil core was cut into twelve small cores, each four inches in length.

Laboratory Studies

Preparation of Soil Samples

The soil samples, placed in polythene bags were brought into the laboratory, air-dried at room temperature and then oven-dried. The samples were ground to pass through a two millimeter sieve and then stored in the same polythene bags until needed. A composite of cores from the five replicates was used for mechanical analysis and organic matter determination. In all the other determinations each core sample was analized and the five replicates then averaged.

Mechanical Analysis

The pipette method, described by Toogood and Peters (1953), was used for the mechanical analysis. The percentages of different fractions; namely, sand, silt, clay and fine clay, are based on

SOIL SURVEY OF THE EDMONTON SHEET

83H WEST HALF

PROVINCE OF ALBERTA

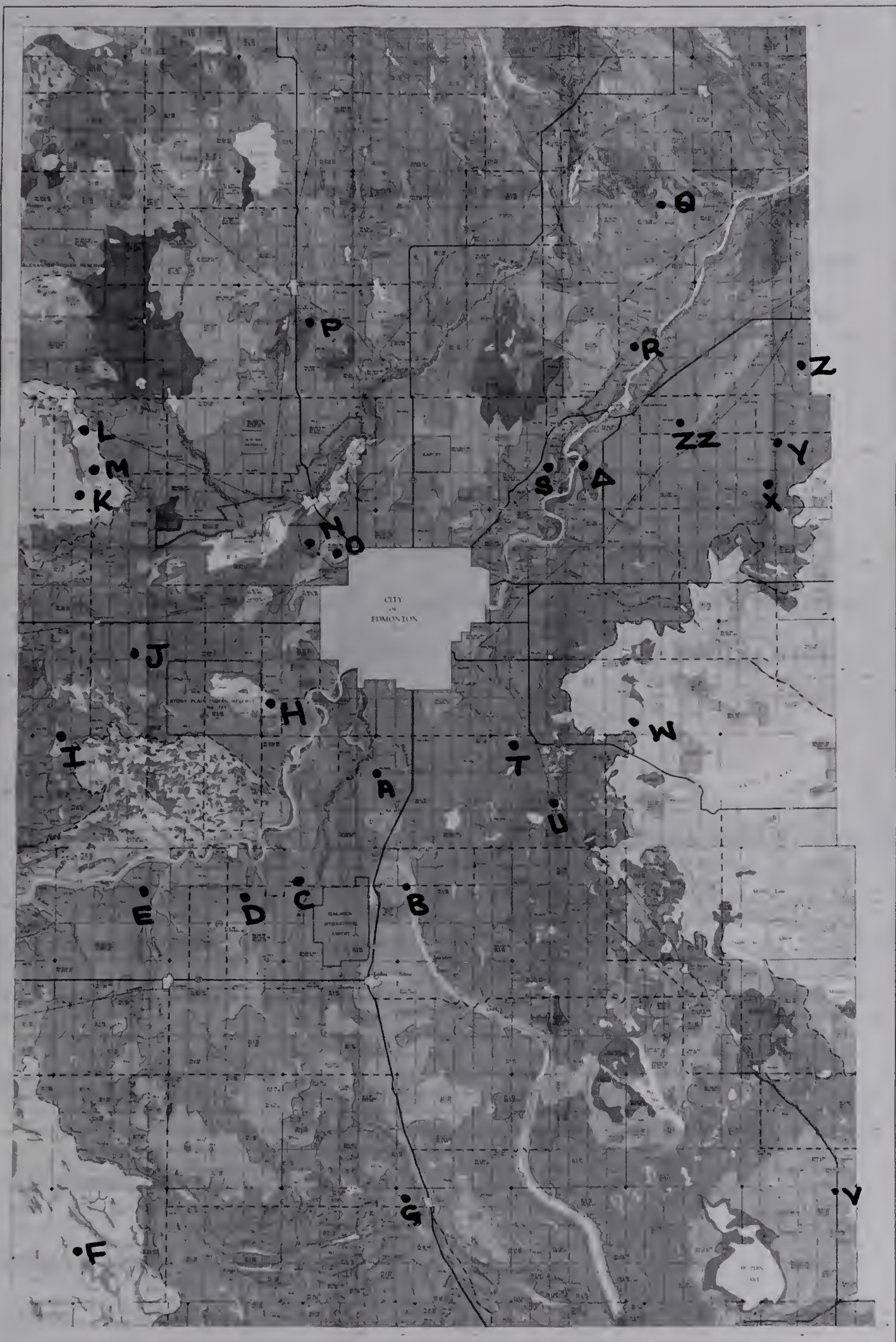

Fig. 2. Map of the Sampling Sites in the Edmonton Area.

oven-dry weight of organic matter, carbonate and soluble salt free soil material.

Bulk Density

The oven-dry weight of the core samples, collected with the Bull Core Sampler or in tin cans, were related to be core volumes to calculate bulk density. Corrections for compaction had to be made in some cases.

Field Capacity

A method using 1/3-atmosphere pressure, as described by the U.S. Salinity Laboratory Staff (1954), was used to determine the field capacity for most of the soils. For the light textured soils, namely, sand, loamy sand and coarse sandy loam, the 1/10-atmosphere pressure was used.

Permanent Wilting Point

The pressure membrane apparatus, as described by U.S. Salinity Laboratory Staff, was used to determine the permanent wilting percentage (lower limit of available water) for all the soil samples. The 15-atmosphere pressure was used.

Available Water Capacity

The difference between field capacity and permanent wilting percentage was used as the available water capacity.

Determination of Organic-Matter Content

The percent organic matter content of each sample was

determined by multiplying the organic carbon percentage by the factor 1.72. Organic carbon was determined by difference between the total and inorganic carbon contents.

Total Carbon

The Leco, model 577-100 carbon analyzer, was used for the determination of total carbon. For this induction furnace, the samples were ground to pass through a 60-mesh sieve.

Calcium Carbonate Equivalent

A smolik calcimeter, in which the estimation of $CaCO_3$ equivalent is based on the measurement of the increase in volume of a closed system due to the release of CO_2 when acid is added to a soil sample, was used for the determination of calcium carbonate equivalent in soil samples ground to $\leq$ 2 mm. size.

Field Studies

Recording the Morphology of the Soils

The twenty-eight soil profiles sampled were exposed to record the morphological characteristics. The detailed descriptions of each profile are given in Table III. The descriptions were based on the features apparent in the exposed profile, on observations made while digging the pit and were checked with descriptions given in the Soil Survey report. The designation of soil horizons is in accordance with the nomenclature adopted by the National Soil Survey Committee of Canada (1965). Textural classes, based on the data obtained from mechanical analyses, were according to the textural

classification diagram devised by Toogood (1958).

Measurement of Precipitation

The M.S.C. Standard rain gauges were used for the measurement of weekly precipitation at ten different sites in 1967. The sites are shown in Fig. 3. The M.S.C. Standard rain gauges were set on the ground with proper exposure. A thin layer of mineral oil was used in each rain gauge to minimize the error for the loss due to evaporation. The precipitation was measured each week, starting from May 15, and continuing for the whole summer until October 10.

Measurement of Soil Moisture

A neutron moisture meter (Nuclear Chicago, Model 5920) was used to make weekly measurements of soil moisture in the profiles at ten different sites in the area (Fig. 3). Two access tubes were installed at each site in the beginning of May, 1967, and readings were taken at depths of 6 inches, 18 inches, 30 inches and 42 inches in each tube. The measurements were made each week from May 15 to October 10, 1967. At the end of October, 1967, samples were collected from each site for the calibration of the neutron probe.

Measurement of Infiltration Rate

For determining the infiltration rate, sites on ten of the soil types under study were selected from chernozemic, solonetzic, podzolic, gleysolic and regosolic soil orders in the area (Fig. 3). At each site the infiltration rate was measured in four replicates

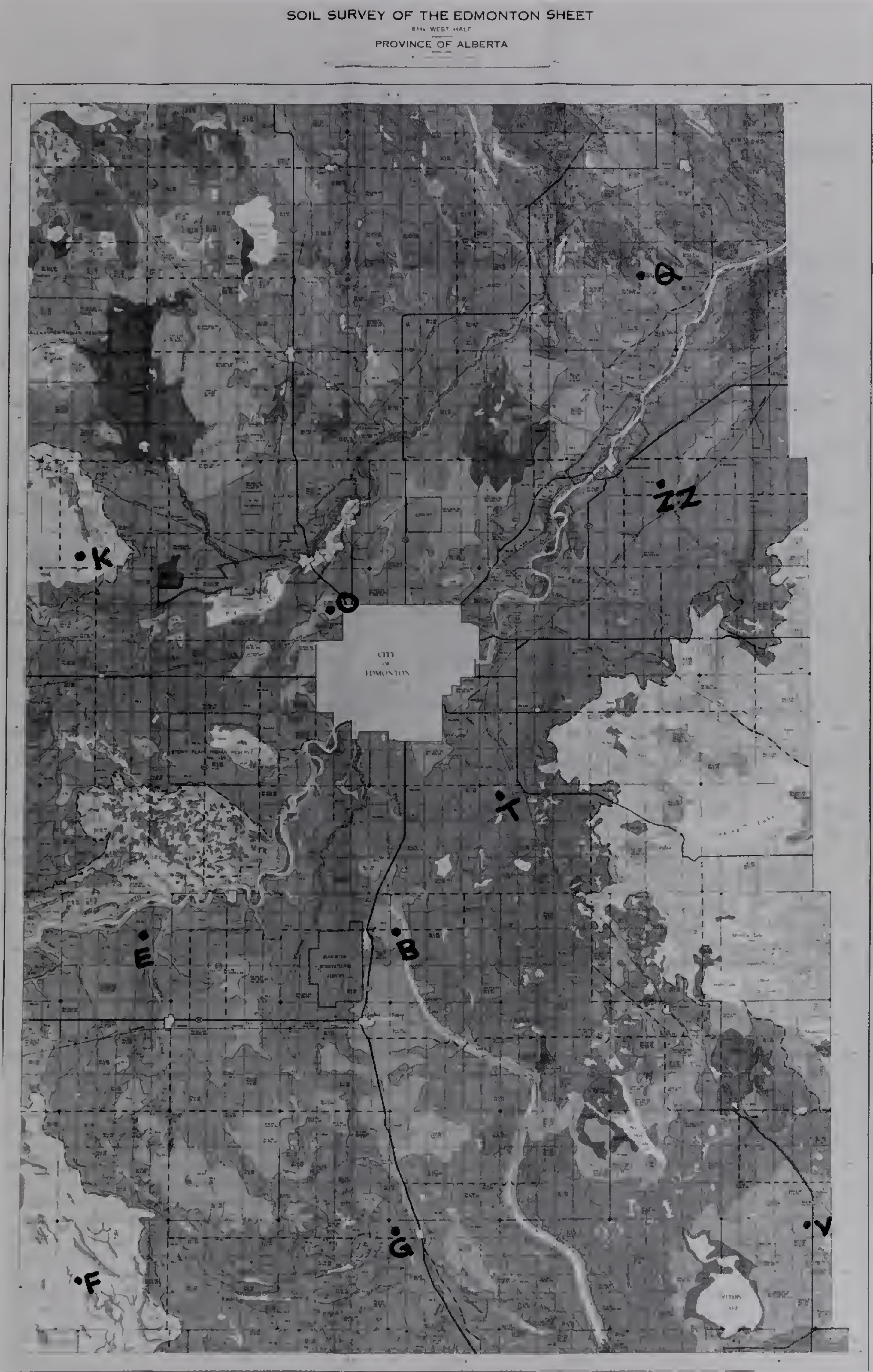

Fig. 3. Map Showing Sites Selected for Field Studies.

and under two types of vegetative cover, namely, grass and cultivated crops. At some sites where it was not possible to get the measurement done under a cultivated crop, cultivated fallow was used.

The concentric ring method was used to measure the infiltration rate (Bertrand, 1965). The concentric rings, 10 cm. high, were made of 14-gauge galvanized iron, sharpened at the lower edge. The diameter of the inner ring was 20 cm. and that of the outer, 30 cm. The rings were driven 2 to 4 cm. into the ground, using a 40 x 40 x 2 cm. plywood board. Graduated cylinders of one litre capacity with an opening at the bottom were used to maintain a 1 cm. head in the inner ring. The outer ring was also filled up to the same height to check the lateral flow of water from the inner ring. Readings of volume infiltrated in the inner ring were recorded at 1, 6, 16, 31, 51 and 81 minutes after a constant head was initially established, and thereafter, every hour till the rate of water entry became constant or practically ceased.

TABLE III

Profile Descriptions of Soils

Site A: NE 24-51-24-W4, LSD-9
Classification: Eluviated Black Chernozem
Series name: Malmo Silty Clay Loam (Mo. SiCL)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-13"	black 10 YR 2/1	SiCL	medium granular	soft
Ahe	13-14"	grayish brown 10 YR 5/1	SiCL	medium platy to coarse weak blocky	friable
Bt	14-28"	brown 10 YR 4/3	C	fine subangular blocky	firm
C	28-48"	dark grayish brown 2.5 Y 4/1	C	massive	firm

Site B: NW 19-50-24-W4, LSD-15
Classification: Black Solodized Solonetz
Series name: Kavanagh Loam (Kv. L)

Ah	0-6"	very dark brown 10 YR 2/2	L to SiL	fine to medium granular	soft
Bnt	6-15"	brown 10 YR 5/3	SiCL	flat top columnar	very hard
Csk	15-24"	grayish brown 10 YR 5/2	C	medium to coarse blocky	very firm
C	24-48"	dark grayish brown 2.5 Y 5/1	C	massive	firm

(Continued)

TABLE III. (Continued)

Site C: SW 30-50-25-W4, LSD-6
Classification: Eluviated Black Chernozem
Series name: Ponoka Loam (Pk.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-17"	black 10 YR 2/1	L	medium granular	soft
Ahe	17-19"	brown 10 YR 5/2	L	weak medium platy	soft
Btj	19-25"	light brown 10 YR 5/3	CL	weak subangular blocky	friable
B C	25-39"	yellowish brown	CL	weak subangular blocky	friable
Ck	39-48"	dark yellowish brown 10 YR 4/4	SiL to CL	massive	friable

Site D: NW 23-50-26-W4, LSD-2
Classification: Eluviated Black Chernozem
Series name: Ponoka Loam (Pk.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ap	0-15"	very dark brown 10 YR 2/2	L	fine granular to weak prismatic	soft
Bt	15-20"	yellowish brown 10 YR 5/4	L to CL	medium prismatic	friable
BC	20-29"	brown 10 Yr 5/3	SL	weak prismatic to massive	friable
Ck	29-48"	dark yellowish brown	SL	massive	friable

(Continued)

TABLE III. (Continued)

Site E: SW 23-50-27-W4, LSD-14
Classification: Eluviated Black Chernozem
Series name: Ponoka Loam (Pk.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-15"	very dark brown 10 YR 2/2	L	fine granular	soft
Ae	15-16"	grayish brown 10 YR 5/2	L	weak platy	soft
Bt	16-22"	yellowish brown 10 YR 5/4	L to CL	weak subangular blocky	friable
BC	22-35"	yellowish brown 10 YR 5/4	SL	loose to massive	friable
Ck	35- "	dark yellowish brown 10 YR 4/4	SiL	massive	friable

Site F: NW 17-47-27-W4, LSD-5
Classification: Orthic Gray Wooded Podzol
Series name: Breton Loam (Bn.L.)

Ap	0-7"	light gray 10 YR 7/2	L	fine platy to fine granular	soft
Ae	7-9"	pale brown 10 YR 6/2	SiL	fine platy	soft
AB	9-17"	light brown 10 YR 5/3	CL	fine subangular blocky	slightly hard
Bt	17-26"	brown 10 YR 5/3	CL	medium blocky	firm
BC	26-48"	dark grayish brown 10 YR 4/2	CL	medium blocky to massive	firm
Ck	48"	dark yellowish brown 10 YR 4/4	CL	massive	firm

(Continued)

TABLE III. (Continued)

Site G: SW 31-47-24-W4, LSD-5
Classification: Orthic Black Chernozem
Series name: Peace Hills Coarse Sandy Loam (Ph.CSL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-18"	very dark gray 10 YR 3/1	CSL	loose granular	loose
Bm	18-30"	yellowish brown 10 YR 5/4	SL	loose granular to weak subangular blocky	loose
C	30-48"	brown 10 YR 5/3	LS	single grain	loose

Site H: NW 7-52-25-W4, LSD-5
Classification: Orthic Gray Wooded Podzol
Series name: Culp Loamy Sand (C.LS)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-1"				
Ae	1-10"	pale brown 10 YR 6/3	LS	weak platy to loose	loose
Bt	10-16"	dark yellowish 10 YR 4/4	SCL	weak subangular blocky to loose	friable
BC	16-30"	yellowish brown 10 YR 5/4	LS	loose	loose
C	30-48"	pale brown 10 YR 6/3	LS	loose	loose

(Continued)

TABLE III. (Continued)

Site I: NW 32-51-27-W4, LSD-14
Classification: Dark Gray Wooded Podzol
Series name: Leith Sandy Loom (Le.SL)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-2"				
Ahe	2-9"	brown to dark brown 10 YR 5/3-4/3	SL	weak prismatic	soft
Ae	9-16"	yellowish brown 10 YR 5/4	LS	weak fine platy	very friable
Bt	16-20"	brown 10 YR 5/3	SCL	weak blocky	slightly hard
Ck	20-26"	grayish brown 10 YR 5/2	LS	loose	loose
C	26"-	brown 10 YR 5/3	LS	loose	loose

Site J: NW 25-52-27-W4, LSD-4
Classification: Orthic Dark Gray Chernozem
Series name: Winterburn Loam (Wb.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ahej	0-18"	very dark grayish brown 10 YR 3/2	L	fine granular	soft
Ahe	18-32"	dark grayish brown 10 YR 4/2	SL	medium granular	very friable
Bt	32-40"	dark yellowish brown 10 YR 4/4	SiL	weak subangular blocky	friable
BC	40-70"	yellowish brown 10 YR 5/4	SiL	massive	friable
C	70"-	brown 10 YR 5/3	SiL	layered	friable

(Continued)

TABLE III. (Continued)

Site K: NW 4-54-27-W4, LSD-4
Classification: Orthic Gray Wooded Podzol
Series name: Cooking Lake Loam (Ck.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-1"				
Ae	1-7"	very pale brown 10 YR 8/3	L	fine platy	soft
Bt_1	7-11"	brown 10 YR 5/3	C to CL	blocky	very fine
Bt_2	11-21"	brown to dark brown 10 YR 5/3-4/3	CL	blocky	firm
BC	21-33"	dark brown 10 YR 4/3	CL	massive	firm
Ck	33-50"	dark gray brown 10 YR 4/2	CL	massive	firm

Site L: SE 28-54-27-W4, LSD-3
Classification: Orthic Gray Wooded Podzol
Series name: Maywood Silty Clay Loam (Mw.SiCL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-3"				
Ae	3-10"	light brownish gray 10 YR 6/2	SiL	medium platy	friable
AB	10-13"	dark grayish brown 2.5 Y 4/2	C	medium to fine blocky	firm
Bt	13-18"	very dark grayish brown 2.5 Y 3/2	C	fine subangular blocky	very firm
Btj	18-33"	dark olive gray 5 Y 3/2	C	fine subangular blocky	firm
Ck	33-39"	olive 2.5 Y 4/4	C	fine subangular blocky	firm
C	39-48"	dark olive gray 2.5 Y 3/2	C	massive	firm

(Continued)

TABLE III. (Continued)

Site M: SE 16-54-27-W4, LSD-16
Classification: Orthic Dark Gray Wooded Podzol
Series name: Uncas Loam (Un.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ahe	0-5"	very dark grayish brown 10 YR 3/2	L	granular to weak platy	soft
Ae	5-8"	dark grayish brown 10 YR 4/2	SL	medium platy	soft
AB	8-10"	dark brown 10 YR 4/3	CL	weak blocky	slightly hard
Bt	10-28"	dark yellowish brown 10 YR 4/4	CL	prismatic to medium subangular blocky	firm
Ck	28-48"	gray brown 10 YR 5/2	L to CL	massive to blocky	firm
C	48"-	dark yellowish brown 10 YR 4/4	SCL	massive	firm

Site N: SE 28-53-25-W4, LSD-3
Classification: Orthic Dark Gray Chernozem
Series name: Mico Silty Clay Loam (Mc.SiCL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-4"	black 10 YR 2/1	SiCL	loose granular	soft
Ahe	4-7"	very dark gray 10 YR 4/1	SiCL	coarse granular	soft
AB	7-9"	grayish brown 10 YR 5/2	CL	subangular blocky	hard
Bt	9-17"	dark brown 10 YR 4/3	C	subangular blocky	very firm
BC	17-31"	dark grayish brown 10 YR 4/2	C	massive	very firm
C	31"-	dark grayish brown 10 YR 4/2	C	massive	very firm

(Continued)

TABLE III. (Continued)

Site O: NE 22-53-25-W4, LSD-15
Classification: Peaty Meadow Gleysol
Series name: Prestville Silty Clay Loam (Pr.SiCL)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-7"				
Ah	7-10"	black 10 YR 2/1	SiL	fine granular	soft
Bg_1	10-15"	dark gray 10 YR 4/1	C	massive to blocky	firm
Bg	15-33"	gray 10 YR 3/1	C	massive	firm
Ck	33"-	gray to dark gray 10 YR 5/1-4/1	C	massive	firm

Site P: SW 27-55-25-W4, LSD-2
Classification: Black Solonetz
Series name: Duagh Silty Clay Loam (Du.SiCL)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-4"	black 10 YR 2/1	SiCL	loose granular	soft
Bnt_1	4-10"	very dark grayish brown 10 YR 3/2	C	columnar to coarse blocky	very hard
Bnt_2	10-18"	brown to dark grayish brown 10 YR 5/3-4/2	C	blocky	very firm
Csk	18-24"	dark grayish brown 2.5 Y 4/2	C	massive	very firm
C	24-48"	dark grayish brown 2.5 Y 4/2	C	massive	very firm

(Continued)

TABLE III. (Continued)

Site Q: NE 22-56-22-W4, LSD-2
Classification: Orthic Regosol
Series name: Dune Sand (D.S.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ahj	0-8"	dark brown 10 YR 4/3	S	loose	loose
AC	8-14"	brown 10 YR 5/3	S	loose	loose
C	14"-	yellowish brown 10 YR 5/4	S	loose	loose

Site R: NW 16-55-22-W4, LSD-9
Classification: Orthic Black Chernozem
Series name: Peace Hills Sandy Loam (Ph.SL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-16"	very dark gray 10 YR 3/1	SL	loose granular	soft
Bm	16-28"	yellowish brown 10 YR 5/4	SL	massive	very friable
BC	28-34"	brown 10 YR 5/3	SL	massive	friable
C	34-48"	gray brown 10 YR 5/2	CL	massive	friable

(Continued)

TABLE III. (Continued)

Site S: NE 9-54-23-W4, LSD-15 and 16
Classification: Black Solodized Solonetz
Series name: Wetaskiwin Silty Clay Loam (Wkn.SiCL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-6"	black 10 YR 2/1	SiCL	fine granular	soft
Ae	6-8"	gray brown 10 YR 5/2	SiCL	platy	friable
Bnt	8-16"	dark grayish brown 10 YR 4/2	C	columnar to fine blocky	very firm
Bntj	16-24"	dark grayish brown 10 YR 4/2	C	massive	very firm
Csk	24-46"	dark grayish brown 2.5 Y 4/2	SiC	massive	firm
C	46"-	dark grayish brown 2.5 Y 4/2	SiC	massive	firm

Site T: SW 32-51-23-W4, LSD-5
Classification: Eluviated Black Chernozem
Series name: Angus Ridge Loam (Ar.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-12"	very dark gray 10 YR 3/1	L	weak coarse prismatic	soft to friable
Ae	12-13"	light brownish gray 10 YR 6/2	L	weak platy	friable
AB	13-22"	brown 10 YR 4/3	CL	medium subangu- lar blocky	friable
Bt	22-31"	brown 10 YR 4/3	CL	subangular blocky	firm
Ck	31-48"	dark grayish brown 10 YR 4/2	CL	massive	firm

(Continued)

TABLE III. (Continued)

Site U: NW 9-51-23-W4, LSD-13
Classification: Orthic Dark Gray Chernozem
Series Name: Falun Loam (Fn.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-5"	black 10 YR 2/1	L	granular	soft
Ahe	5-10"	dark grayish brown 10 YR 4/2	L	weak platy	soft
AB	10-15"	dark yellowish brown 10 YR 4/4	CL	medium subangular blocky	friable
Bt	15-36"	dark grayish brown 10 YR 4/2	CL	medium subangular blocky	friable
Ck	36-48"	dark brown 10 YR 3/3	CL	massive	friable
C	48"-	very dark gray brown 10 YR 3/2	CL	massive	friable

Site V: NE 35-47-21-W4, LSD-14
Classification: Black Solodized Solonetz
Series name: Camrose Loam (Cam.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-6"	very dark brown 10 YR 2/2	L	fine granular	soft
Ae	6-8"	gray brown 10 YR 5/2	L	fine platy	soft
Bnt_1	8-16"	dark brown 10 YR 4/3	CL	columnar	very firm
Bnt_2	16-23"	dark yellowish brown 10 YR 4/4	CL	columnar to blocky	firm
Csk	23-48"	dark grayish brown 2.5 Y 4/2	CL	massive	firm
C	48"-	dark grayish brown 10 YR 4/2	L	massive	slightly firm

(Continued)

TABLE III. (Continued)

Site W: NW 5-52-22-W4, LSD-5
Classification: Orthic Carey Wooded Podzol
Series name: Cooking Lake Loam (Ck.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
L-H	0-2"				
Ae	2-8"	very pale brown 10 YR 8/3	L	platy	very friable
Bt_1	8-12"	brown 10 YR 5/3	CL	blocky to weak columnar	firm
Bt_2	12-22"	dark brown 10 YR 4/3	CL	blocky	firm
BC	22-34"	dark brown 10 YR 4/3	CL	massive	firm
Ck	34-48"	dark gray brown 10 YR 4/2	CL	massive	firm

Site X: SW 9-54-21-W4, LSD-5
Classification: Eluviated Black Chernozem
Series name: Angus Ridge Loam (Ar.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-20"	very dark gray 10 YR 3/1	L	granular	soft
Ae	20-21"	light brownish gray 10 YR 6/2	L	weak platy	friable
AB	21-30"	brown 10 YR 5/4	CL	medium to sub-angular blocky	friable
Bt	30-38"	dark yellowish brown 10 YR 4/4	CL	medium prismatic	firm
Ck	38"-	dark grayish brown 10 YR 4/2	CL	massive	firm

(Continued)

Table III. (Continued)

Site Y: NE 21-54-21-W4, LSD-9
Classification: Orthic Black Chernozem
Series name: Navarre Silty Clay Loam (Nv.SiCL.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-16"	black 10 YR 2/1	SiCL	granular	soft
AB	16-19"	gray brown 10 YR 5/2	SiC	granular	very friable
Btj	19-30"	light brownish gray 2.5 Y 6/2	SiC	fine subangular blocky	friable
Ck	30-50"	dark grayish brown 2.5 Y 4/2	SiCL	massive	friable

Site Z: NE 2-55-21-W4, LSD-9and 10
Classification: Eluviated Black Chernozem
Series name: Angus Ridge Loam (Ar.L.)

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-12"	black 10 YR 2/1	L	granular	soft
Ae	12-13"	light brownish gray 10 YR 6/2	L	fine platy	soft
AB	13-20"	yellowish brown 10 YR 4/3	CL	medium subangular blocky	friable
Bt	20-28"	dark yellowish brown 10 YR 4/4	CL	medium prismatic to subangular blocky	firm
Ck	28"-	dark grayish brown 10 YR 4/2	CL	massive	firm

(Continued)

TABLE III. (Continued)

Site ZZ: NE 27-54-22-W4, LSD-6
Classification: Eluviated Black Chernozem
Series name: Malmo Silty Clay Loam

Horizon	Depth	Colour Dry	Texture	Structure	Consistence
Ah	0-10"	black 10 YR 2/1	SiCL	granular	soft
Ae	10-12"	dark grayish brown 10 YR 4/2	SiCL	medium platy	friable
Bt	12-32"	dark brown 10 YR 4/3	C	subangular blocky	firm
Ck	32-40"	dark grayish brown 2.5 Y 4/2	C	massive	firm
C	40-48"	dark grayish brown 2.5 Y 4/2	C	massive	firm

Site △: NW 13-54-23-W4, LSD-5
Classification: Orthic Regosol
Series name: Alluvium Sandy Loam (Au.SL.)

L-H	0-1"				
C	1-48"	brown 10 YR 5/4	SL	massive	soft

Meteorological Studies

Selection of Stations

The choice of stations for obtaining the meteorological data was based primarily upon the number of weather parameters recorded at the individual station and the geographic location of these stations. Since the monthly averages of minimum and maximum temperature, mean temperature, dry-bulb temperature, relative humidity, wind mileage, hours of sunshine, and precipitation were needed for estimations of potential evapotranspiration and finally moisture balance, the stations had to be recording all these parameters, and at the same time had to be representative of the study area.

In consultation with Professor R.W. Longley, the following meteorological stations were chosen. These stations are well distributed within and outside of the area (Fig. 4).

1. Calmar
2. Camrose
3. Edmonton Industrial Airport
4. Edmonton International Airport
5. Ranfurly
6. Sion

Obtaining Data

Data from these stations were used for the estimation of potential evapotranspiration and subsequently for the computations of moisture balance. The Edmonton Industrial Airport is the only

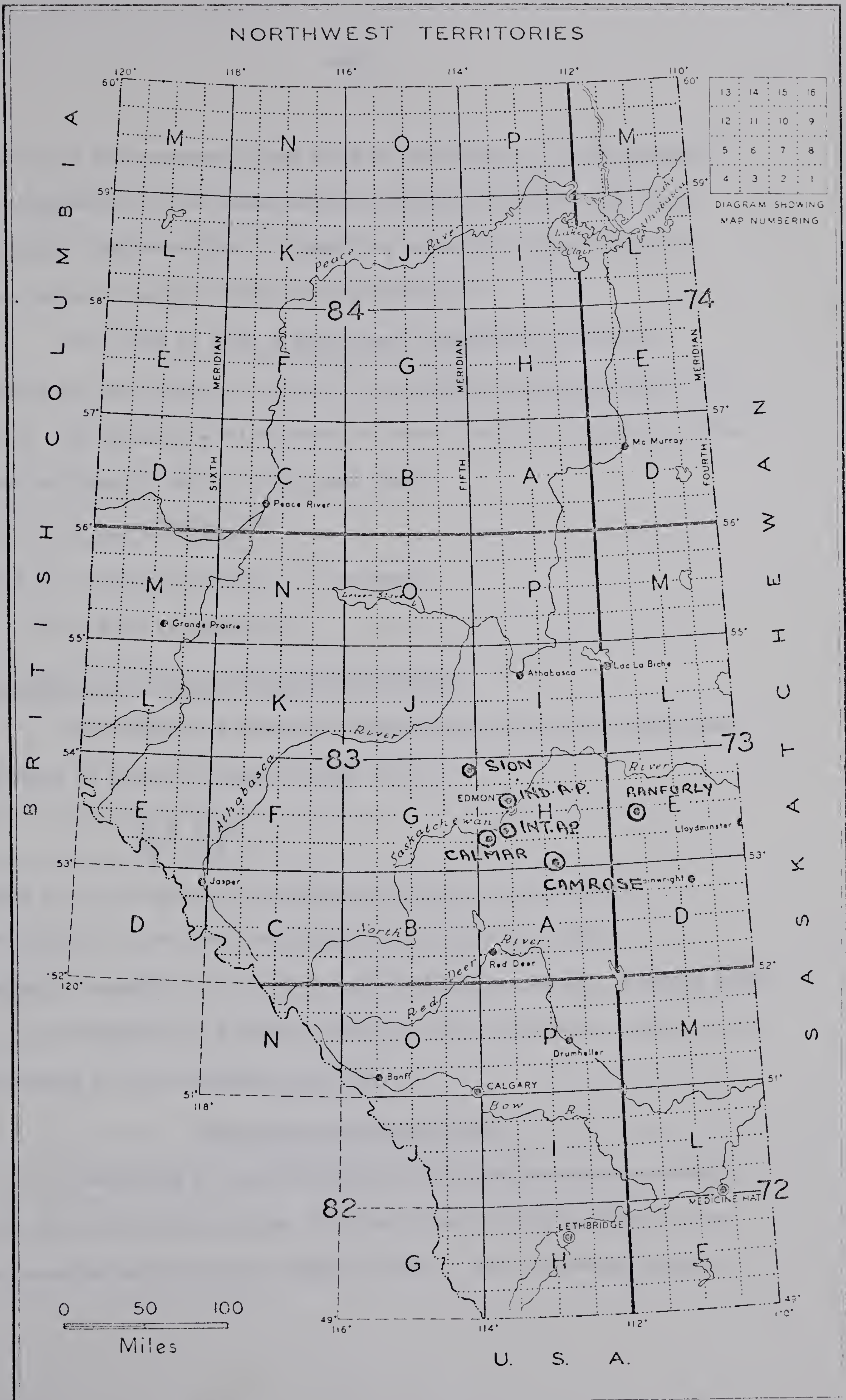

Fig. 4. Location of Meteorological Stations Used in the Study.

station in the area which had data on radiation. It was assumed that radiation at the other stations would be similar and these data were therefore used in computing potential evapotranspiration for all the six stations in the area.

The data on wind mileage were recorded at different heights at the Edmonton Industrial and Edmonton International airports. To estimate wind mileage at lower levels of two meters, the formula given by Sutton (1953) was used:

$$U_1/U_2 = (Z_1/Z_2)^{1/7}$$

where U_1 = wind at height Z_1 (2 meters),

U_1 = wind at height Z_2.

Estimation of Potential Evapotranspiration

For computing potential evapotranspiration the generalized equation is given by Penman (1963) to be:

$$E = \frac{\frac{\Delta}{\gamma} H + Ea}{\frac{\Delta}{\gamma} + x}$$

where E is the potential evapotranspiration, γ is constant (=0. 62197) of the wet- and dry-bulb psychrometer equation, x is variable dependent on stomatal geometry and day-length, assumed equal to 1, as proposed by Businger (1956), and the remaining terms are as described in the following sections.

The vapour-pressure term

Values of Δ , the variation of saturation vapour-pressure over water with temperature, and the formula are presented in the Smithsonian Meteorological Tables (1958). The following formula

was used by the computer to determine Δ at mean air temperature T:

$$\Delta = \frac{e_w}{T^2} \quad (6790.5 - 5.02808\ T + 4916.8 \times 10^{-.0304\ T}\ T^2$$

$$+ \ 174209 \times 10^{-4} - \frac{1302.88}{T})$$

where e_w is the saturation vapour-pressure over water.

<u>The heat budget H</u>

The heat budget equation was presented by Penman in the form:

$$H = R_I \ (1-r) - R_B$$

where R_I is the short-wave radiation, r is the albedo coefficient (assumed equal to 0.25 for a green crop), and R_B is the long-wave radiation outward.

Where radiation observations are not available, Penman proposed the following equations for estimations:

$$R_I = R_A \ (0.18 + 0.55\ n/N)$$

and $$R_B = \sigma T^4 \ (0.56 - 0.09\ e_d^{1/2}) \quad (0.10 + 0.90\ n/N)$$

where R_A is the theoretical maximum solar radiation* received at the top of the earth's atmosphere, n/N is the ratio of actual to possible hours of sunshine, σT^4 is the theoretical black-body radiation at mean air temperature (degrees Kelvin) with expressed in evaporation equivalents, (equal to 1.98 mm. $H_2O/cm.^2/day/^o K^4$), e_d is the mean vapour-pressure of the atmosphere (mm. Hg.). To convert radiation data, presented in langleys to evaporation equivalent, divide by the factor 59 (1 mm. evaporation per

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*For values of R_A at latitude intervals of 10 degrees and at 23-day intervals, see the Smithsonian Meteorological Tables.

day = 59 calories/cm.^{2}/day).

Drying power of the air Ea

The Ea factor of the Penman equation was estimated by the following equation:

$$Ea = 0.35\ (1 + U/100)\ (e_w - e_d)$$

where U is the wind speed in miles per day at a height of two meters, e_w is the saturation vapour-pressure at mean air temperature, and e_d is the mean vapour-pressure of the atmosphere.

To determine e_d, the values of saturation vapour-pressure over water, e_w, were needed. The values of e_w are given in the Smithsonian Meteorological Tables, however, it is easier in a computer program to compute these values rather than getting them from the tables. The Goff-Gratch (1946) formula was used, and the program is as presented in the appendix.

Values of e_d were then calculated as follows:

$$e_d = e_w \times \text{Relative humidity}$$

where e_w is the saturation vapour-pressure over water. To conform

to the original sources, pressure units have been expressed in millibars. An average barometric pressure, p, of 935 mb. has been assumed for all the stations in the study area.

Before entering pressure quantities into the Penman equation, a factor of 0.02953 was used to convert millibars to inches of Hg.

The determination of potential evapotranspiration is a lengthy process, however, the computation was greatly facilitated by the use of a digital computer. The program (given in the Appendix) for estimating the monthly potential evapotranspiration was written up to accept monthly averages of observations.

Estimation of Actual Evapotranspiration

For the year 1967 the actual evapotranspiration was computed by using the measured precipitation and soil moisture data in the following equation:

$$\text{Actual Evapotranspiration} = \text{Precipitation} \pm \text{Change in soil moisture} - \text{Runoff} - \text{Deep percolation.}$$

It was observed during the period of May to September, 1967 that runoff did not occur. This was to be expected since the hazard of runoff is low (Verma and Toogood, 1968).

During the growing season the soils of this area normally contain much less moisture than their moisture holding capacity; frequently the amount of soil moisture is close to the wilting point (Toogood, 1963). Therefore, the chances of deep percolation are also negligible.

Thus, the last two components of the equation were ignored in computation of actual evapotranspiration.

Statistical Studies

Simple correlation, multiple correlation and regression analyses were performed to relate available water capacity with the physical properties of soils. The procedure used is as outlined by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Available Water Capacity of Soils

The available water capacities in twenty-two soil types of the Edmonton area are shown in Table IV. The values show large differences, ranging from 1.7 inches per 4 ft. in Culp Loamy Sand to 18 inches per 4 ft. in Kavanagh Loam. Most of the soils have available water capacities in the range of 8 to 12 inches except coarse textured and solonetzic soils which show very low and very high values, respectively. The data in Table IV do not show any distinct effect of soil order on the available water capacities of soils. In general, with the exception of Kavanagh Loam, the silty clay loam soils have higher available water capacity values as compared to loam, sandy loam and sandy soils. The causes for variation in A.W.C. will be discussed later in connection with correlation studies presented in Table V.

The analysis of variance of the available water capacity data (Appendix A) shows that the soil types differ significantly from one to another. However, the differences are not large enough between the different sites of the same soil type to make the variance significant. Angus Ridge Loam, Cooking Lake Loam, Malmo Silty Clay Loam, and Ponoka Loam soils, which represent individually a larger acreage as compared to other soil types in the Edmonton area, were sampled from more than one site to find the variation in available soil moisture. Since the mechanical components, organic-matter and bulk density vary in the profiles of the same soil type, the available water capacity also varies consequently for the cores taken from the same depth of the different profiles of a soil type.

TABLE IV

Field Capacity*, Permanent Wilting Point* and Available Water Capacity* Values for Soils of the Edmonton Area

Soil Order	Soil Type	Site	F.C. in.	P.W.P. in.	A.W.C. in.
Chernozemic	Angus Ridge Loam	T	16.0	7.8	8.2
		X	14.7	7.0	7.7
		Z	15.7	7.9	7.8
Chernozemic	Falun Loam	U	19.0	9.9	9.1
Chernozemic	Malmo Silty Clay Loam	A	18.6	9.2	9.4
		ZZ	19.3	10.2	9.1
Chernozemic	Mico Silty Clay Loam	N	23.6	11.1	12.5
Chernozemic	Navarre Silty Clay Loam	Y	18.0	9.3	8.7
Chernozemic	Peace Hills Coarse Sandy Loam	G	7.5	3.3	4.2
Chernozemic	Peace Hills Sandy Loam	R	14.7	8.3	6.4
Chernozemic	Ponoka Loam	C	18.2	8.7	9.5
		D	15.8	6.1	9.7
		E	17.6	7.7	9.9
Chernozemic	Winterburn Loam	J	14.3	5.7	8.6
Gleysolic	Prestville Silty Clay Loam	O	23.2	13.7	9.5
Podzolic	Breton Loam	F	14.3	5.9	8.4
Podzolic	Cooking Lake Loam	K	18.2	8.4	9.8
		W	22.9	12.5	10.4
Podzolic	Culp Loamy Sand	H	3.2	1.5	1.7
Polzolic	Leith Sandy Loam	I	5.7	2.1	3.6

*Inches of water in upper four feet of soil profile.

Table IV. (Continued)

Soil Order	Soil Type	Site	F.C. in.	P.W.P. in.	A.W.C. in.
Podzolic	Maywood Silty Clay Loam	L	23.4	12.2	11.2
Podzolic	Uncas Loam	M	16.6	7.8	8.8
Regosolic	Alluvium Sandy Loam	D	13.9	5.2	8.7
Regosolic	Dune Sand	Q	3.8	2.0	1.8
Solonetzic	Camrose Loam	V	18.9	9.5	9.4
Solonetzic	Duagh Silty Clay Loam	P	22.0	11.0	11.0
Solonetzic	Kavanagh Loam	B	34.9*	16.5	18.4
Solonetzic	Wetaskiwin Silty Clay Loam	S	17.0	8.0	9.0

* This value leads to erroneous estimates of inches of water held (See Table VI). It results from failure of the pressure plate technique for soils of this kind.

TABLE V

Coefficients of Correlation †

	3*	4*	5*	6*	Bulk density gm./cc.	Sand %	Silt %	Coarse Clay %	Fine Clay %	Total Clay %	Organic Matter %
1*	.87	.83	.59	.66	.04	-.77	.63	.62	.43	.57	.05
2*	.70	.93	.40	.73	.49	-.61	.43	.56	.41	.53	-.32
3*		.82	.91	.83	-.12	-.84	.53	.81	.62	.78	.31
4*			.64	.92	.43	-.71	.36	.74	.62	.74	-.23
5*				.80	-.24	-.73	.34	.80	.67	.80	.47
6*					.32	-.72	.25	.83	.77	.88	-.10

† Levels of Sig.: 5% = 0.113
1% = 0.148

1* Available water capacity (dry wt. percentage).

2* Available water capacity (volume percentage).

3* Field capacity (dry wt. percentage).

4* Field capacity (volume percentage).

5* Permanent wilting point (dry st. percentage).

6* Permanent wilting point (volume percentage).

However, the total available water capacity per 4 feet for these profiles at different sites within the same soil type does not vary significantly. Bartelli and Peters (1959) and Salter, Berry and Williams (1966) have also reported the similar consistency in the available moisture within a soil type in the soils of Illinois and of the United Kingdom, respectively.

Table VI shows the available water capacity expressed as percent of oven dry weight and as inches of available water on 320 different cores taken from different depths of twenty-eight soil profiles of the Edmonton area. The variation in the available water capacity of these cores is not only evident between the cores from different soil types but also between the cores from different depths of the same site. This variation in available water capacity values of different cores is, no doubt, largely due to the variation in physical properties of different horizons within a soil profile. Similar variation in the values of the available water capacity of samples from different depths has been reported by Salter, Berry and Williams (1966) and Salter and Williams (1967).

The available water capacity values on a volume basis (inches) show a different trend to their respective values shown as percentage of oven dry weight (Table VI). However, this is to be expected because of the variation in the bulk density values in a soil profile. These increase with depth while AWC values frequently show decreases.

The available water capacity of a soil is affected by the physical, chemical and pedological properties of its profile. This

view is supported by the studies of Wilcox and Spilsbury (1941), Jamison and Kroth (1958), Bartelli and Peters (1959), Lund (1959), Salter and Williams (1965a, 1965b), Salter, Berry and Williams (1966), and Salter and Williams (1967). However, the amount of available water in any disturbed soil sample is mainly determined by the particle size distribution, organic-matter, bulk density and moisture characteristics of the sample. Therefore, in this study, attempts were made to correlate the available water capacity with various soil separates, organic-matter, bulk density, field capacity and permanent wilting point. The different coefficients of correlation are shown in Table V.

The most important features of the data in Table V are the significant positive correlations between available water capacity and field capacity, both on dry weight percentage basis and volume percentage basis. The correlation coefficient between available water capacity and permanent wilting point is not quite so high. The general view that silty soils are high in available water, is also strongly supported by the high positive correlation between available water capacity and silt percentage. This may be one of the reasons for silty clay loam soils being high in available soil moisture (Table IV). This has also been reported by Lund (1959) and Salter and Williams (1967).

The correlation coefficients between available water capacity and coarse clay are as high as between available water capacity and silt. This is contradictory to the work of Bartelli and Peters (1959) and Lund (1959), where they have reported low correlation

coefficients. Most of the soils in this study are medium to coarse in texture, and clay content would tend to provide favourable structure and this increase available water capacity. However, the data have no details to make this point any clearer.

The significant negative correlation between available water capacity and sand percentage indicates that there is a decrease in available water capacity with an increase in sand content. This follows the conclusions of Jamison and Kroth (1958); Bartelli and Peters (1959); Lund (1959); Salter and Williams (1956b); Salter, Berry and Williams (1966); and Salter and Williams (1967).

The correlation between available water capacity (dry weight percentage) and bulk density is very low, indicating that there is no relationship between the two. However, there is a significant positive correlation between available water capacity (volume percentage) and bulk density.

The relationship between available water capacity and organic-matter is just reverse to the ones reported by Jamison and Kroth (1958). However, they studied this relationship in heavy textured soils, where organic matter would have resulted in the formation of stable microaggregates of silt size.

The available water capacity (dry weight percentage), when correlated with field capacity (dry weight percentage), permanent wilting point (dry weight percentage), bulk density, and with percentages of sand, silt, coarse clay, fine clay, total clay and organic matter, gave a multiple correlation value of 0.995. The

multiple correlation, when calculated between the available water capacity (volume percentage) and field capacity (volume percentage), permanent wilting point (volume percentage), bulk density; and percentages of sand, silt, coarse clay, find clay, total clay and organic-matter, was slightly less with a value of 0.916. The calculated multiple from values of field capacity, permanent wilting point, bulk density, sand, silt, coarse clay, find clay, total clay and organic-matter as follows:

$$\begin{aligned} \text{A.W.C.} \ (\text{dry wt. \%}) = {} & -0.40 + 0.97\ (\text{F.C.*}) - 1.02\ (\text{P.W.P.*}) + 0.17 \\ & (\text{Bulk density}) + 0.003\ (\text{Sand}) + 0.009\ (\text{Silt}) + \\ & 0.004\ (\text{Coarse clay}) + 0.015\ (\text{Fine clay}) + 0.008 \\ & (\text{Total clay}) + 0.058\ (\text{Organic matter}). \text{-------}(1). \end{aligned}$$

$$\begin{aligned} \text{A.W.C.} \ (\text{volume \%}) = {} & -0.17 + 0.94\ (\text{F.C.**}) - 0.97\ (\text{P.W.P.**}) + \\ & 0.96\ (\text{Bulk density}) - 0.009\ (\text{Sand}) + 0.006 \\ & (\text{Silt}) - 0.006\ (\text{Coarse clay}) - 0.022\ (\text{Fine clay}) \\ & + 0.029\ (\text{Total clay}) + 0.002\ (\text{Organic matter}). \text{--}(2). \end{aligned}$$

The values of field capacity and permanent wilting point have been included in the calculation of multiple linear regression because of the high coefficients of correlation between available water capacity and these values. Though these values are not available in soil survey reports, they can be estimated from the bulk density and mechanical analyses data available in soil survey reports. Similar miltiple regressions have been reported by Wilcox and Spilsbury (1941); Salter, Berry and Williams (1966); and Salter and

* Dry weight percentage
** Volume percentage

Williams (1967); however, they have used a smaller number of variables.

Soil structure is also a significant factor for determining the quantity of available soil moisture and may alter the effect of other physical properties such as texture and bulk density. However, it is very difficult to evaluate the quantitative effect of soil structure.

The available water capacity is an expression of two moisture characteristics of a soil profile, namely, field capacity and permanent wilting point. These two are equally important and should be discussed separately.

Field Capacity

The field capacity values (upper limit of available soil moisture) for soils of the Edmonton area are given in Table IV. The values range from 3.2 inches per 4 ft. in Culp Loamy Sand to 34.9 inches per 4 ft. in Kavanagh Loam. The Kavanagh Loam has a very high field capacity, which could probably be due to higher salt content in the profile.

The field capacity varied significantly among cores taken from different depths of the same profile (Table VI). The variation is also evident between the cores taken from the same depth from different soil types. This variation is expected since the physical properties which affect the field capacity are different in the horizons of different soil types.

The field capacity for different cores when expressed as percentage of volume gave a different trend as compared to the

values expressed as percentage of dry weight. This is mainly due to the fact that bulk density did not have a parallel trend to the dry weight percentage values of field capacity.

The Field capacity, like available water capacity, is affected by the various physical proerties of soil profile and, therefore, the coefficients of correlation were calcutlated (Table V).

The field capacity was found to have a high positive correlation with the values of permanent wilting point. The correlation was higher when both the variables had the same units.

The correlation between field capacity (dry weight percentage) and bulk density was negative and low. However, the correlation increased to a significant positive value when calculated between field capacity (volume percentage) and bulk density.

As expected the field capacity had a high negative correlation with sand. The increase in amount of sand brought a linear decrease in the quantity of moisture content at field capacity. A similar relationship has been reported by Wilcox and Spilsbury (1941); Jamison and Kroth (1958); Lund (1959); Salter, Berry and Williams (1966); and Salter and Williams (1967).

The positive correlations (0.53 and 0.36) between field capacity and silt are less than those between field capacity and clay fractions. This means that the field capacity increases with an increase in fine and coarse clay contents.

The field capacity seems to be affected slightly by organic matter. The correlation coefficient between the two is 0.31 when field capacity is expressed as percentage of dry weight and -0.23

when it is expressed as percentage of volume.

The relationship between field capacity (dry weight percentage and volume percentage) and other physical variables gave a multiple correlation of 0.916 and 0.899. The following multiple linear regression equations were calculated for the estimation of field capacity from bulk density, sand, silt, coarse clay, fine clay, total clay and organic matter:

F.C. (dry weight %) = -6.2 + 5.2 (Bulk density) + 0.10 (Sand) + 0.22 (Silt) + 0.3 (Coarse clay) - 0.16 (Fine clay) + 0.42 (Total clay) + 0.98 (Organic matter). --------------------(3).

F.C. (Volume %) = -40 + 26 (Bulk density) + 0.09 (Sand) + 0.38 (silt) + 0.40 (Coarse clay) - 0.33 (Fine clay) + 0.76 (Total clay) + 0.28 (Organic matter). --------------------------(4).

Similar equations but with lesser number of variables have been worked out by Wilcox and Spilsbury (1941); Salter, Berry and Williams (1966); and Salter and Williams (1967).

<u>Permanent Wilting Point</u>

The permanent wilting point is the lower limit of available water in the soils. The values are given in Table IV.

As in the case of available water capacity and field capacity values, these is also a variability in the values of permanent wilting point of one soil type to another. The values also showed variability in the cores of the same soil type taken from different

depths of the profile (Table VI).

The permanent wilting point values, when correlated with various physical properties of soil profile, gave different coefficients of correlation as compared to those between available water capacity and the physical properties of soil; and to those between field capacity and physical properties of soil. Therefore, the changes in permanent wilting point, as a result of changed physical properties of soil profile, are not parallel to the changes in field capacity (Table V).

The permanent wilting point, when compared to field capacity, has higher values of coefficients of correlation for sand and silt. Therefore, the permanent wilting point values, as compared to field capacity, decrease with a lower rate with an increase in sand content and increase with a higher rate with an increase in clay content. This relationship explains the reason for the high available water capacity in silty soils. The similar relationship is evident when the correlation coefficients between each of these and organic-matter are compared. This has also been reported by Wilcox and Spilsbury (1941); Jamison (1956); Jamison and Kroth (1958); Bartelli and Peters (1959); Lund (1959); Salter and Williams (1965b); Salter, Berry and Williams (1966); and Salter and Williams (1967).

The permanent wilting point, both dry weight percentage and volume percentage, when related with bulk density, sand, silt, coarse clay, fine clay, total clay and soil organic matter, gave very high multiple correlation values of 0.946 and 0.933. The multiple regression values between permanent wilting point and these variables

can be used to estimate the permanent wilting point as follows:

$$\text{P.W.P. (dry wt. \%)} = -4.1 + 2.9\ (\text{Bulk density}) + 0.001\ (\text{Sand}) + 0.036\ (\text{Silt}) + 0.025\ (\text{Coarse clay}) + 0.11\ (\text{Fine clay}) + 0.13\ (\text{Total clay}) + 0.97\ (\text{Organic matter}). \text{---} (5).$$

$$\text{P.W.P. (volume \%)} = -14 + 11\ (\text{Bulk density}) + 0.001\ (\text{Sand}) + 0.060\ (\text{Silt}) + 0.26\ (\text{Coarse clay}) + 0.031\ (\text{Fine clay}) + 0.30\ (\text{Total clay}) + 0.40\ (\text{Organic matter}). \text{---} (6).$$

Grouping of Soil Types Based on Their Available Water Capacities

Table VII shows the various numerical values of available water capacity and the list of soil types for each value. Since the purpose of the study was to determine the moisture balance patterns in the Edmonton area, these particular values of available water capacity for the soils are listed against each value. The table shows that most of the loam and silty clay loam soils fall in the available water capacity values of 8, 9, and 10 inches.

TABLE VI

Soil Moisture, Bulk Density, Mechanical Analysis and Organic Matter Data of Soils of the Edmonton Area

Site A (Malmo Silty Clay Loam)

Core No.	F.C.* %	F.C.* 1 in.	P.W.P* %	P.W.P* 1 in.	A.W.C.* %	A.W.C.* 1 in.	D_b gm/cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1**	31	1.0	14	0.5	17	0.5	0.81	27	44	13	16	29	12.6
2	31	1.1	16	0.6	15	0.5	0.88	27	45	14	14	28	9.7
3	28	1.3	13	0.6	15	0.7	1.12	26	44	17	13	30	6.0
4	25	1.4	13	0.7	12	0.7	1.42	27	39	17	17	34	2.2
5	25	1.5	13	0.8	12	0.7	1.59	30	33	18	19	37	1.0
6	24	1.6	12	0.8	12	0.8	1.62	30	21	31	18	49	0.9
7	26	1.7	14	0.9	12	0.8	1.67	31	34	19	16	35	0.9
8	26	1.7	14	0.9	12	0.8	1.68	32	34	18	16	34	0.7
9	26	1.8	13	0.9	13	0.9	1.77	32	34	17	17	34	0.6
10	26	1.8	12	0.8	14	1.0	1.76	33	37	18	12	30	0.6
11	27	1.8	13	0.8	14	1.0	1.66	32	34	18	16	34	0.7
12	27	1.9	12	0.9	15	1.0	1.78	35	34	18	13	31	0.9

(continued)

*Each of the three moisture contents is expressed in two ways: (a) in percentage dry weight of soil; (b) in inches of water per core of soil profile.

**Cores four inches in length numbered consecutively to a depth of 48 inches.

TABLE VI. (Continued)

Site B (Kavanagh Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	28	1.0	12	0.4	16	0.6	0.92	26	53	10	11	21	7.7
2	28	1.3	13	0.6	15	0.7	1.18	20	55	5	20	25	4.6
3	39	2.1	21	1.1	18	1.0	1.34	17	41	23	19	42	3.4
4	50	2.7	23	1.3	27	1.4	1.36	7	55	23	25	48	2.4
5	38	2.2	23	1.3	15	0.9	1.45	3	43	29	25	54	1.2
6	40	2.4	23	1.4	17	1.0	1.48	2	43	32	22	55	1.1
7	54	3.3	25	1.6	29	1.7	1.55	3	43	28	26	54	0.6
8	59	4.0	28	1.9	31	2.1	1.69	3	43	33	21	54	0.5
9	58	3.7	25	1.6	33	2.1	1.60	4	40	37	19	56	0.8
10	61	4.2	25	1.7	36	2.4	1.71	4	45	26	25	51	1.0
11	61	4.0	25	1.7	36	2.3	1.66	4	40	27	29	56	1.2
12	60	4.1	26	1.8	34	2.3	1.68	5	42	33	20	53	1.2

(Continued)

TABLE VI. (Continued)

Site C (Ponoka Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	32	1.1	17	0.6	15	0.5	0.90	25	48	6	21	27	10.8
2	29	1.1	15	0.6	14	0.5	0.95	26	49	5	20	25	6.9
3	26	1.2	16	0.7	10	0.5	1.16	26	48	7	19	26	4.5
4	24	1.2	13	0.6	11	0.6	1.23	30	46	7	17	24	2.4
5	22	1.1	11	0.5	11	0.6	1.32	34	45	6	15	21	1.0
6	21	1.1	9	0.5	12	0.6	1.32	31	47	8	14	22	1.1
7	24	1.4	12	0.7	12	0.7	1.46	24	49	10	17	27	0.7
8	30	1.6	13	0.7	17	0.9	1.31	14	56	12	18	30	1.5
9	35	1.8	17	0.9	18	0.9	1.26	4	62	15	19	34	1.0
10	38	2.1	19	1.1	19	1.0	1.39	2	54	23	21	44	1.1
11	38	2.2	16	0.9	22	1.3	1.44	2	54	23	21	44	0.9
12	41	2.4	16	1.0	25	1.4	1.48	1	55	23	21	44	1.2

(Continued)

TABLE VI. (Continued)

Site D (Ponoka Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.P.* %	A.W.P.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	30	0.9	12	0.3	18	0.6	0.79	44	35	11	10	21	9.0
2	32	1.2	13	0.5	19	0.7	0.91	39	41	9	11	20	10.0
3	30	1.4	11	0.5	19	0.9	1.18	39	41	9	11	20	5.3
4	28	1.4	8	0.4	20	1.0	1.30	41	41	8	10	18	3.8
5	26	1.5	9	0.6	17	0.9	1.45	36	41	5	18	23	2.2
6	26	1.6	9	0.6	17	1.0	1.49	37	42	4	17	21	1.9
7	23	1.5	9	0.6	14	0.9	1.61	45	35	6	14	20	2.1
8	20	1.3	8	0.5	12	0.8	1.64	49	34	3	14	17	1.9
9	18	1.2	8	0.5	10	0.7	1.67	51	30	4	15	19	1.7
10	19	1.3	8	0.6	11	0.7	1.69	49	33	4	14	18	1.8
11	18	1.2	7	0.5	11	0.7	1.76	49	34	5	12	17	1.3
12	19	1.3	7	0.5	12	0.8	1.70	48	32	7	13	20	1.5

(Continued)

TABLE VI. (Continued)

Site E (Ponoka Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	27	1.0	13	0.5	14	0.5	0.93	36	41	9	14	23	6.9
2	24	1.1	11	0.5	13	0.6	1.18	33	43	10	14	24	4.2
3	22	1.2	10	0.5	12	0.7	1.41	28	47	9	16	25	0.9
4	22	1.4	11	0.7	11	0.7	1.51	36	36	9	19	28	0.7
5	18	1.1	9	0.5	9	0.6	1.51	48	30	8	14	22	0.6
6	17	1.0	8	0.5	9	0.5	1.54	55	23	8	14	22	0.5
7	19	1.2	8	0.5	11	0.7	1.58	56	23	8	13	21	0.7
8	18	1.1	8	0.5	10	0.6	1.55	48	30	8	14	22	1.0
9	28	1.8	13	0.8	15	1.0	1.58	26	47	16	11	27	1.7
10	36	2.2	17	1.0	19	1.2	1.50	3	59	20	18	38	0.6
11	38	2.2	15	0.8	23	1.4	1.48	1	67	15	17	32	0.4
12	38	2.2	15	0.8	23	1.4	1.48	1	67	15	17	32	0.4

(Continued)

TABLE VI (Continued)

Site F (Breton Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	22	1.0	6	0.3	16	0.7	1.13	34	55	8	3	11	3.8
2	19	1.0	4	0.3	15	0.7	1.31	37	52	7	4	11	2.0
3	15	1.0	4	0.3	11	0.7	1.60	36	51	8	5	13	0.4
4	15	1.0	6	0.4	9	0.6	1.69	52	39	2	7	9	0.4
5	17	1.2	7	0.5	10	0.7	1.72	50	31	8	11	19	0.6
6	16	1.1	7	0.5	9	0.6	1.76	57	26	7	10	17	0.5
7	13	1.0	6	0.4	7	0.6	1.89	68	19	6	7	13	0.4
8	17	1.2	8	0.5	9	0.7	1.84	62	21	7	10	17	0.4
9	20	1.4	9	0.7	11	0.7	1.83	60	16	12	12	24	0.4
10	20	1.4	10	0.7	10	0.7	1.80	58	19	11	12	23	0.4
11	19	1.5	8	0.6	11	0.8	1.94	64	16	10	10	20	0.4
12	20	1.5	10	0.7	10	0.8	1.84	59	19	10	12	22	0.6

(Continued)

TABLE VI. (continued)

Site G (Peace Hills Coarse Sandy Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm/cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1**	21	1.3	9	0.6	12	0.7	1.05	81	8	6	5	11	4.5
2	18	1.2	8	0.5	10	0.7	1.12	79	13	5	3	8	6.2
3	15	1.1	7	0.5	8	0.6	1.18	76	15	5	4	9	4.6
4	11	0.8	6	0.4	5	0.4	1.23	76	12	6	6	12	2.9
5	13	0.9	4	0.3	9	0.6	1.19	89	1	6	4	10	2.3
6	12	0.8	5	0.4	7	0.4	1.19	84	8	4	4	8	3.3
7	8	0.6	3	0.2	5	0.4	1.21	84	7	5	4	9	1.1
8	11	0.8	5	0.4	6	0.4	1.22	95	1	3	1	4	2.6

** At sites G, H, I and Q, tin cans were used to take representative cores from the 0-6 inch depth, 6-12 inch depth, etc.

(continued)

TABLE VI. (Continued)

Site H (Culp Loamy Sand)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	5	0.4	2	0.2	3	0.2	1.34	91	3	4	2	6	0.5
2	6	0.4	2	0.2	4	0.2	1.35	93	2	3	2	5	0.6
3	6	0.5	2	0.2	4	0.3	1.32	91	4	3	2	5	0.7
4	4	0.4	2	0.2	3	0.2	1.34	91	5	2	2	4	0.2
5	5	0.4	2	0.2	3	0.2	1.32	90	8	1	1	2	0.5
6	5	0.4	2	0.2	3	0.2	1.29	92	5	1	2	3	0.7
7	4	0.3	2	0.2	2	0.2	1.32	95	3	1	1	2	0.5
8	4	0.3	2	0.2	2	0.2	1.41	95	4	0	1	1	0.1

(Continued)

TABLE VI. (Continued)

Site I (Leith Sandy Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	12	0.8	6	0.4	6	0.4	1.02	90	9	1	0	1	3.8
2	10	0.8	4	0.3	6	0.5	1.23	89	8	2	1	3	2.0
3	11	0.8	3	0.2	8	0.6	1.17	86	12	1	1	2	1.9
4	7	0.6	2	0.2	5	0.4	1.39	88	10	1	1	2	0.3
5	6	0.5	2	0.2	4	0.3	1.36	90	4	3	3	6	0.2
6	8	0.6	3	0.2	5	0.4	1.40	89	4	3	4	7	0.2
7	10	0.8	4	0.3	6	0.5	1.37	86	5	3	6	9	0.2
8	10	0.8	4	0.4	6	0.4	1.38	87	4	3	6	9	0.2

(Continued)

TABLE VI. (Continued)

Site J (Winterburn Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	24	0.9	12	0.4	12	0.5	0.98	25	55	8	12	20	5.2
2	24	1.0	11	0.5	13	0.5	1.02	24	55	9	12	21	4.5
3	27	1.1	11	0.4	16	0.7	1.03	23	57	7	13	20	3.8
4	22	0.9	10	0.4	12	0.5	1.04	22	57	8	13	21	3.9
5	22	1.0	10	0.4	12	0.6	1.13	20	60	7	13	20	2.8
6	21	1.0	9	0.4	12	0.6	1.23	19	60	7	14	21	2.0
7	20	1.1	8	0.5	12	0.6	1.39	24	52	12	12	24	1.0
8	17	1.0	8	0.5	9	0.5	1.45	33	50	7	10	17	0.8
9	21	1.3	8	0.5	13	0.8	1.53	35	46	8	11	19	0.8
10	26	1.5	9	0.5	17	1.0	1.42	23	57	8	12	20	0.7
11	31	1.7	10	0.6	21	1.1	1.39	8	68	9	15	24	0.5
12	33	1.8	11	0.6	22	1.2	1.40	3	74	10	13	23	0.6

(Continued)

TABLE VI. (Continued)

Site K (Cooking Lake Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic Matter %
1	20	1.0	7	0.3	13	0.7	1.30	30	54	11	5	16	2.2
2	20	1.2	7	0.4	13	0.8	1.50	38	42	11	9	20	1.1
3	20	1.4	12	0.8	8	0.6	1.65	31	43	13	13	26	0.4
4	20	1.4	11	0.8	9	0.6	1.70	38	33	13	16	29	0.8
5	21	1.4	11	0.8	10	0.6	1.67	43	28	13	16	29	0.4
6	22	1.6	12	0.8	10	0.8	1.77	42	28	15	15	30	0.8
7	25	1.7	10	0.7	15	1.0	1.77	41	31	14	14	28	0.3
8	24	1.7	10	0.7	14	1.0	1.77	41	30	14	15	29	0.6
9	25	1.8	11	0.8	14	1.0	1.78	42	31	12	15	27	0.6
10	24	1.7	12	0.9	12	0.8	1.81	41	32	8	19	27	0.5
11	23	1.6	10	0.7	13	0.9	1.77	42	35	9	14	23	0.1
12	24	1.7	10	0.7	14	1.0	1.83	40	39	8	13	21	0.4

(Continued)

TABLE VI. (Continued)

Site L (Maywood Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	28	1.2	12	0.5	16	0.7	1.04	14	62	12	12	24	6.1
2	26	1.4	12	0.6	14	0.8	1.30	14	62	10	14	24	4.3
3	27	1.6	16	1.0	11	0.6	1.48	13	42	16	29	45	1.0
4	31	1.8	19	1.1	12	0.7	1.51	11	36	17	36	53	1.0
5	32	2.0	18	1.2	14	0.8	1.55	7	41	22	30	52	1.3
6	34	2.1	19	1.2	15	0.9	1.52	6	42	24	28	52	0.9
7	36	2.2	20	1.2	16	1.0	1.51	6	44	25	25	50	1.5
8	39	2.3	20	1.1	19	1.2	1.48	5	46	20	29	49	0.8
9	40	2.4	20	1.2	20	1.2	1.52	4	46	27	23	50	1.6
10	38	2.3	17	1.0	21	1.3	1.52	6	50	24	20	44	2.1
11	33	2.1	15	1.0	18	1.2	1.61	17	44	20	19	39	0.6
12	29	2.0	1.5	1.1	14	0.9	1.69	25	39	20	16	36	0.4

(Continued)

TABLE VI. (Continued)

Site M (Uncas Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	23	1.1	10	0.5	13	0.6	1.20	36	48	8	8	16	7.0
2	18	1.1	7	0.4	11	0.7	1.53	40	44	7	9	16	1.3
3	18	1.2	9	0.6	9	0.6	1.68	40	35	7	18	25	0.6
4	21	1.3	11	0.7	10	0.6	1.65	39	34	7	20	27	0.4
5	20	1.3	10	0.6	10	0.7	1.67	38	37	7	18	25	1.1
6	22	1.5	10	0.7	12	0.8	1.70	37	38	7	18	25	0.7
7	21	1.5	10	0.7	11	0.8	1.74	40	36	7	17	24	0.8
8	22	1.5	10	0.7	12	0.8	1.77	39	37	6	18	24	1.2
9	20	1.5	9	0.7	11	0.8	1.79	44	31	9	16	25	0.5
10	21	1.6	10	0.8	11	0.8	1.89	43	31	12	14	26	0.6
11	20	1.5	9	0.7	11	0.8	1.80	43	33	11	13	24	0.6
12	20	1.5	8	0.7	12	0.8	1.90	44	31	11	14	25	0.7

(Continued)

TABLE VI. (Continued)

Site N (Mico Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter
1	32	1.2	17	0.6	15	0.6	0.93	6	57	20	17	37	8.3
2	29	1.3	14	0.6	15	0.7	1.08	6	59	18	17	35	4.3
3	29	1.5	16	0.9	13	0.6	1.34	4	42	22	32	54	1.5
4	30	1.8	18	1.1	12	0.7	1.45	4	38	21	37	58	1.5
5	32	1.9	20	1.2	12	0.7	1.50	2	43	20	35	55	1.3
6	34	2.0	19	1.1	15	0.9	1.48	1	51	17	31	48	1.1
7	38	2.3	16	1.0	22	1.3	1.48	1	59	17	23	40	1.1
8	40	2.3	18	1.0	22	1.3	1.43	1	61	14	24	38	1.1
9	40	2.2	16	0.9	24	1.3	1.36	3	59	19	19	38	0.9
10	41	2.2	16	0.9	25	1.3	1.37	1	65	19	15	34	1.3
11	42	2.4	15	0.8	27	1.6	1.38	2	57	22	19	41	0.7
12	43	2.5	18	1.0	25	1.5	1.46	3	56	22	19	41	0.8

(Continued)

TABLE VI. (Continued)

Site O (Prestville Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	64	1.3	48	1.0	16	0.3	0.52	12	46	31	11	42	30.1
2	46	1.2	27	0.7	19	0.5	0.68	14	41	29	16	45	15.4
3	31	1.7	17	0.9	14	0.8	1.37	17	31	19	33	52	1.7
4	34	1.8	19	1.1	15	0.8	1.37	21	20	16	43	59	0.8
5	35	2.0	21	1.2	14	0.8	1.40	22	16	16	46	62	0.3
6	35	2.0	20	1.1	15	0.9	1.47	23	15	20	42	62	0.9
7	35	2.0	19	1.1	16	0.9	1.50	23	15	21	41	62	0.6
8	35	2.0	22	1.2	13	0.8	1.48	18	14	26	42	68	0.9
9	37	2.2	22	1.3	15	0.9	1.45	11	18	32	39	71	0.9
10	38	2.2	23	1.3	15	0.9	1.43	7	19	34	40	74	1.2
11	41	2.3	24	1.4	17	0.9	1.42	3	21	36	40	76	1.2
12	42	2.4	24	1.4	18	1.0	1.42	2	25	34	39	73	0.7

(Continued)

TABLE VI. (Continued)

Site P (Duagh Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	52	1.3	33	0.8	19	0.5	0.62	6	59	19	16	35	19.3
2	29	1.3	15	0.7	14	0.6	1.11	3	70	15	12	27	1.9
3	31	1.6	18	0.9	13	0.7	1.26	2	48	16	34	50	0.9
4	31	17	17	0.9	14	0.8	1.34	1	48	21	30	51	1.3
5	32	1.8	18	1.0	14	0.8	1.41	3	45	24	28	52	1.4
6	32	1.9	16	1.0	16	0.9	1.45	8	46	19	27	46	0.7
7	33	2.0	17	1.0	16	1.0	1.53	8	48	20	24	44	0.7
8	33	2.1	16	1.0	17	1.1	1.57	14	41	21	24	45	0.8
9	33	2.1	15	0.9	18	1.2	1.60	17	48	15	20	35	0.6
10	32	2.1	15	0.9	17	1.2	1.66	19	50	15	16	31	0.8
11	30	2.1	12	0.9	18	1.2	1.75	24	48	15	13	28	0.7
12	26	2.0	12	0.9	14	1.1	1.85	32	44	13	11	24	0.1

(Continued)

TABLE VI. (Continued)

Site Q (Dune Sand)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	13	0.8	8	0.5	5	0.3	1.08	93	1	1	5	6	4.7
2	8	0.6	4	0.3	4	0.3	1.33	92	1	4	3	7	1.7
3	5	0.4	2	0.2	3	0.2	1.39	93	1	3	3	1	0.5
4	4	0.4	2	0.2	2	0.2	1.42	93	0	4	3	7	0.1
5	5	0.4	3	0.2	2	0.2	1.35	94	0	4	2	6	0.0
6	5	0.4	3	0.2	2	0.2	1.30	92	1	4	3	7	0.4
7	5	0.4	2	0.2	3	0.2	1.33	93	1	4	2	6	0.1
8	4	0.4	2	0.2	2	0.2	1.32	94	1	2	3	5	0.0

(Continued)

TABLE VI. (Continued)

Site R (Peace Hills Sandy Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	24	0.8	16	0.5	8	0.3	0.81	48	33	9	10	19	9.2
2	24	0.8	16	0.5	8	0.3	0.84	45	36	7	12	19	7.6
3	24	0.9	17	0.6	7	0.3	0.94	41	38	8	13	21	8.1
4	23	0.9	15	0.6	8	0.3	1.00	42	38	7	13	20	7.0
5	22	1.0	14	0.7	8	0.3	1.21	43	30	10	17	27	3.6
6	23	1.2	13	0.7	10	0.5	1.36	42	28	8	22	30	2.0
7	24	1.4	14	0.8	10	0.6	1.47	34	31	12	23	35	1.9
8	25	1.5	13	0.8	12	0.7	1.51	29	34	16	21	37	1.4
9	25	1.5	14	0.9	11	0.6	1.52	32	36	14	18	32	0.9
10	25	1.6	13	0.8	12	0.8	1.57	36	38	11	15	26	1.2
11	24	1.6	11	0.8	13	0.8	1.59	28	44	12	16	28	1.1
12	23	1.5	9	0.6	14	0.9	1.60	25	54	8	13	21	0.5

(Continued)

TABLE VI. (Continued)

Site S (Wetaskiwin Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	32	1.0	19	0.6	13	0.4	0.75	29	52	11	8	19	11.8
2	18	0.8	10	0.4	8	0.4	1.11	31	48	11	10	21	3.2
3	20	1.1	11	0.6	9	0.5	1.35	43	33	11	11	13	0.9
4	21	1.3	12	0.7	9	0.6	1.56	42	29	14	15	29	0.9
5	23	1.5	13	0.8	10	0.7	1.69	42	30	12	16	28	0.5
6	22	1.5	10	0.7	12	0.8	1.70	44	34	8	14	22	1.4
7	24	1.7	12	0.8	12	0.9	1.75	38	36	12	14	26	1.1
8	24	1.7	10	0.7	14	1.0	1.75	41	39	10	10	20	0.6
9	22	1.6	10	0.7	12	0.9	1.82	45	36	10	9	19	0.6
10	22	1.6	10	0.7	12	0.9	1.87	47	35	9	9	18	0.6
11	23	1.6	9	0.6	14	1.0	1.82	48	34	9	9	18	0.4
12	22	1.6	9	0.7	13	0.9	1.88	46	36	10	8	18	0.5

(Continued)

TABLE VI. (Continued)

Site T (Angus Ridge Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter
1	24	0.9	13	0.5	11	0.4	0.90	30	44	11	15	26	6.3
2	24	0.9	12	0.5	12	0.4	0.94	28	43	13	16	29	3.5
3	23	1.1	12	0.6	11	0.5	1.16	27	43	10	20	30	2.0
4	24	1.3	12	0.7	12	0.6	1.31	25	43	11	21	32	1.2
5	25	1.5	12	0.7	13	0.8	1.48	23	39	16	22	38	1.0
6	25	1.5	12	0.7	13	0.8	1.50	26	44	9	21	30	1.2
7	25	1.6	12	0.8	13	0.8	1.62	24	45	12	19	31	1.0
8	22	1.5	12	0.8	10	0.7	1.60	25	44	13	18	31	1.0
9	21	1.3	11	0.7	10	0.6	1.57	34	41	10	15	25	1.1
10	23	1.3	11	0.6	12	0.8	1.54	33	44	10	13	23	1.2
11	26	1.6	11	0.6	15	0.9	1.56	30	43	13	14	27	1.4
12	23	1.5	10	0.6	13	0.9	1.60	33	44	10	13	23	1.0

(Continued)

TABLE VI. (Continued)

Site U (Falun Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	31	1.1	18	0.6	13	0.5	0.89	18	41	17	24	41	8.1
2	32	1.3	17	0.7	15	0.6	1.01	16	39	19	26	45	5.5
3	35	1.8	21	1.1	14	0.7	1.30	8	32	20	40	60	3.0
4	35	1.9	21	1.2	14	0.7	1.36	6	34	20	40	60	1.6
5	34	2.0	19	1.1	15	0.9	1.49	5	43	23	29	52	1.2
6	31	1.9	16	1.0	15	0.9	1.49	13	44	19	24	43	0.9
7	30	1.9	14	0.9	16	1.0	1.60	22	41	18	19	37	1.1
8	29	19	14	0.9	15	1.0	1.63	27	37	17	19	36	1.8
9	23	1.6	12	0.8	11	0.8	1.73	35	37	14	14	28	1.5
10	17	1.2	8	0.6	9	0.6	1.77	50	31	10	9	19	0.4
11	16	1.2	7	0.5	9	0.7	1.80	50	33	9	8	17	0.7
12	16	1.2	7	0.5	9	0.7	1.84	51	31	9	9	18	0.8

(Continued)

TABLE VI. (Continued)

Site V (Camrose Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	28	1.0	20	0.7	8	0.3	0.90	40	38	12	10	22	11.2
2	25	1.1	14	0.6	11	0.5	1.15	42	35	10	13	23	5.2
3	23	1.3	12	0.7	11	0.6	1.41	43	31	10	16	26	2.9
4	24	1.4	12	0.7	12	0.7	1.45	38	32	12	18	30	2.5
5	27	1.6	14	0.8	13	0.8	1.51	31	35	14	20	34	1.5
6	27	1.7	13	0.9	14	0.8	1.57	31	32	17	20	37	1.6
7	26	1.7	12	0.8	14	0.9	1.65	33	36	17	14	31	1.4
8	25	1.7	12	0.8	13	0.9	1.71	35	37	14	14	28	1.5
9	26	1.8	13	0.9	13	0.9	1.75	36	39	11	14	25	1.3
10	27	1.9	13	0.9	14	1.0	1.79	34	42	9	14	24	1.3
11	26	1.8	12	0.8	14	1.0	1.79	35	43	7	15	22	0.8
12	26	1.9	12	0.9	14	1.0	1.81	35	42	7	16	23	0.9

(Continued)

TABLE VI. (Continued)

Site W (Cooking Lake Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	31	1.1	15	0.5	16	0.6	0.88	20	55	12	13	25	7.9
2	26	1.3	14	0.7	12	0.6	1.27	14	50	14	22	36	2.2
3	33	1.7	21	1.1	12	0.6	1.32	8	33	19	40	59	1.6
4	38	2.0	23	1.2	15	0.8	1.35	7	38	13	42	55	1.5
5	36	2.0	21	1.2	15	0.8	1.42	10	25	27	38	65	1.2
6	35	2.1	21	1.3	14	0.8	1.49	9	31	26	34	60	1.1
7	36	2.2	21	1.3	15	0.9	1.54	5	32	29	34	63	1.0
8	36	2.3	20	1.3	16	1.0	1.56	8	29	30	33	63	1.4
9	35	2.3	19	1.2	16	1.1	1.62	17	31	26	26	52	1.4
10	32	2.2	14	0.9	18	1.3	1.72	30	29	19	22	41	1.4
11	25	1.8	12	0.9	13	0.9	1.79	34	30	18	18	36	2.2
12	26	1.9	12	0.9	14	1.0	1.82	36	30	18	16	34	1.1

(Continued)

TABLE VI. (Continued)

Site X (Angus Ridge Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	29	1.0	18	0.6	11	0.4	0.84	31	47	10	12	22	10.3
2	26	0.9	14	0.5	12	0.4	0.83	30	49	8	13	21	7.9
3	24	0.9	13	0.5	11	0.4	0.92	28	50	7	15	22	6.1
4	27	1.0	13	0.5	14	0.5	0.95	29	51	6	14	20	5.0
5	25	1.0	11	0.5	14	0.6	1.08	30	51	7	12	19	3.8
6	26	1.3	10	0.5	16	0.8	1.22	30	49	7	14	21	1.4
7	24	1.4	10	0.6	14	0.8	1.39	28	52	5	15	20	1.2
8	23	1.3	10	0.6	13	0.7	1.43	29	49	7	15	22	1.0
9	24	1.5	11	0.7	13	0.8	1.55	32	36	15	17	32	0.6
10	24	1.5	11	0.7	13	0.8	1.56	31	40	15	14	29	0.8
11	23	1.4	10	0.6	13	0.8	1.57	35	37	16	12	28	1.1
12	23	1.4	11	0.7	12	0.6	1.56	36	36	16	12	28	1.8

(Continued)

TABLE VI. (Continued)

Site Y (Navarre Silty Clay-Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	37	1.0	27	0.7	10	0.3	0.68	39	28	19	19	33	13.1
2	35	1.0	24	0.7	11	0.3	0.76	42	30	24	4	28	11.6
3	33	1.4	22	0.9	11	0.5	1.02	43	29	25	3	28	9.2
4	27	1.4	15	0.8	12	0.6	1.26	41	31	24	3	28	3.6
5	26	1.6	13	0.8	13	0.8	1.53	37	33	14	16	30	1.2
6	25	1.5	13	0.8	12	0.7	1.53	42	28	11	19	30	0.9
7	19	1.3	9	0.6	10	0.7	1.74	62	21	5	12	17	0.9
8	23	1.5	11	0.7	12	0.8	1.69	47	29	8	16	24	0.7
9	27	1.8	13	0.8	14	1.0	1.68	39	29	13	19	32	1.0
10	31	2.0	14	0.9	17	1.1	1.64	31	34	14	21	35	1.1
11	27	1.9	13	0.9	14	1.0	1.75	45	23	16	16	32	0.4
12	24	1.6	11	0.7	13	0.9	1.69	56	21	10	13	23	0.6

(Continued)

TABLE VI. (Continued)

Site Z (Angus Ridge Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	27	0.9	18	0.6	9	0.3	0.85	53	26	9	12	21	10.2
2	20	0.7	12	0.4	8	0.3	0.89	50	30	9	11	20	4.9
3	18	0.9	9	0.4	9	0.5	1.25	47	32	9	12	21	2.5
4	20	1.1	11	0.6	9	0.5	1.39	46	25	11	18	29	1.3
5	20	1.2	11	0.7	9	0.5	1.56	44	26	11	19	30	0.6
6	21	1.5	11	0.8	10	0.7	1.73	45	25	12	18	30	0.7
7	22	1.6	11	0.8	11	0.8	1.77	44	26	13	17	30	0.5
8	22	1.6	11	0.8	11	0.8	1.78	44	22	16	18	34	0.8
9	22	1.5	10	0.7	12	0.8	1.74	46	30	12	12	24	0.6
10	22	1.6	10	0.7	12	0.9	1.80	45	34	11	10	21	0.3
11	21	1.5	10	0.7	11	0.8	1.84	48	29	13	10	23	0.1
12	22	1.6	10	0.7	12	0.9	1.81	47	31	12	10	22	0.3

(Continued)

TABLE VI. (Continued)

Site ZZ (Malmo Silty Clay Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	49	1.2	34	0.8	14	0.4	0.61	15	35	26	24	50	21.3
2	35	1.0	25	0.7	11	0.3	0.68	16	34	25	25	50	12.7
3	28	1.1	16	0.6	12	0.5	0.98	19	28	18	35	53	5.6
4	29	1.4	14	0.7	15	0.7	1.25	18	31	16	35	51	3.5
5	30	1.6	15	0.8	15	0.8	1.32	20	26	17	37	54	2.8
6	30	1.8	15	0.9	15	0.9	1.53	20	25	18	37	55	2.8
7	29	1.8	17	1.0	12	0.8	1.50	24	26	22	28	50	2.4
8	30	1.7	16	0.9	14	0.8	1.49	24	26	21	28	49	1.7
9	30	1.8	15	0.9	15	0.9	1.51	27	24	23	26	49	1.3
10	30	1.9	15	0.9	15	1.0	1.54	27	24	24	25	49	1.1
11	30	2.0	14	1.0	16	1.0	1.61	27	25	23	25	48	1.5
12	31	2.0	15	1.0	16	1.0	1.61	28	26	20	26	46	1.4

(Continued)

TABLE VI. (Continued)

Site Δ (Alluvium Sandy Loam)

Core no.	F.C.* %	F.C.* in.	P.W.P.* %	P.W.P.* in.	A.W.C.* %	A.W.C.* in.	D_b gm./cc.	Sand %	Silt %	Coarse clay %	Fine clay %	Total clay %	Organic matter %
1	24	1.0	11	0.4	13	0.6	1.06	23	49	15	13	28	3.7
2	25	1.1	10	0.4	15	0.7	1.13	23	50	15	12	27	3.6
3	25	1.2	10	0.5	15	0.7	1.22	19	48	22	11	33	3.1
4	26	1.1	10	0.4	16	0.7	1.11	15	57	11	17	28	3.0
5	28	1.1	11	0.4	17	0.7	1.03	14	58	17	11	28	3.4
6	27	1.0	11	0.4	16	0.6	1.00	16	54	19	11	30	3.2
7	25	1.1	10	0.4	15	0.7	1.14	20	53	16	11	27	2.3
8	24	1.1	9	0.4	15	0.7	1.17	22	49	21	8	29	2.4
9	30	1.3	10	0.4	20	0.9	1.07	9	67	18	6	24	3.0
10	30	1.3	13	0.6	17	0.7	1.06	11	69	14	6	20	3.4
11	29	1.3	12	0.5	17	0.8	1.15	13	66	14	7	21	3.0
12	26	1.3	10	0.4	16	0.9	1.25	16	65	12	7	19	2.6

(Continued)

TABLE VII

Grouping of the Soil Types Based on A.W.C.

A.W.C. inches 4 feet	Soil types
2	Culp Loamy Sand and Dune Sand
4	Leith Sandy Loam and Peace Hills Coarse Sandy Loam
6	Peace Hills Sandy Loam
8	Angus Ridge Loam and Breton Loam
9	Alluvium Sandy Loam, Camrose Loam, Falus Loam, Malmo Silty Clay Loam, Navarre Silty Clay Loam, Uncas Loam, Wetaskiwin Silty Clay Loam, and Winterburn Loam
10	Cooking Lake Loam, Ponoka Loam, and Prestville Silty Clay Loam
11	Duagh Silty Clay Loam and Maywood Silty Clay Loam
12	Mico Silty Clay Loam
18*	Kavanagh Loam

* This value is open to question as discussed on page 103.

Infiltration Rates in the Soils of the Edmonton Area

The infiltration curves (Fig. 5, 6 and 7) are averages for each soil type for the four replicates. On three of the curves in Fig. 5 the standard deviations are shown by vertical lines to indicate the degree of variability in measurement. All curves show a high initial rate and a rapid decrease during the first half hour, regardless of the soil type or history or cultivation. The shape of the curves during this half hour period is no doubt governed by the initial physical condition of the surface soil, namely its moisture content, temperature, presence of cracks, texture, structure and porosity. Table VIII shows that in general most soils had ample available storage capacity at the start of the infiltration measurements. The curves start levelling off from 40 to 60 minutes after the start. The slope of the curves and the time when they start levelling off may be determined by a number of factors: available water capacity, pore geometry, breakdown of soil aggregates, viscosity of water, swelling of clays, and increased length of channels. When a constant rate is reached the infiltration rate is probably governed by water movement through the least permeable layer above the wetting front. This also had been mentioned by Hanks and Bowers (1962) and Staple and Gupta (1966). It is assumed that temperature effects on viscosity were insignificant in these studies since the range of soil temperature (Table VIII) was not large and water at fairly constant temperature was used.

The moisture content of the profile probably affected the rates

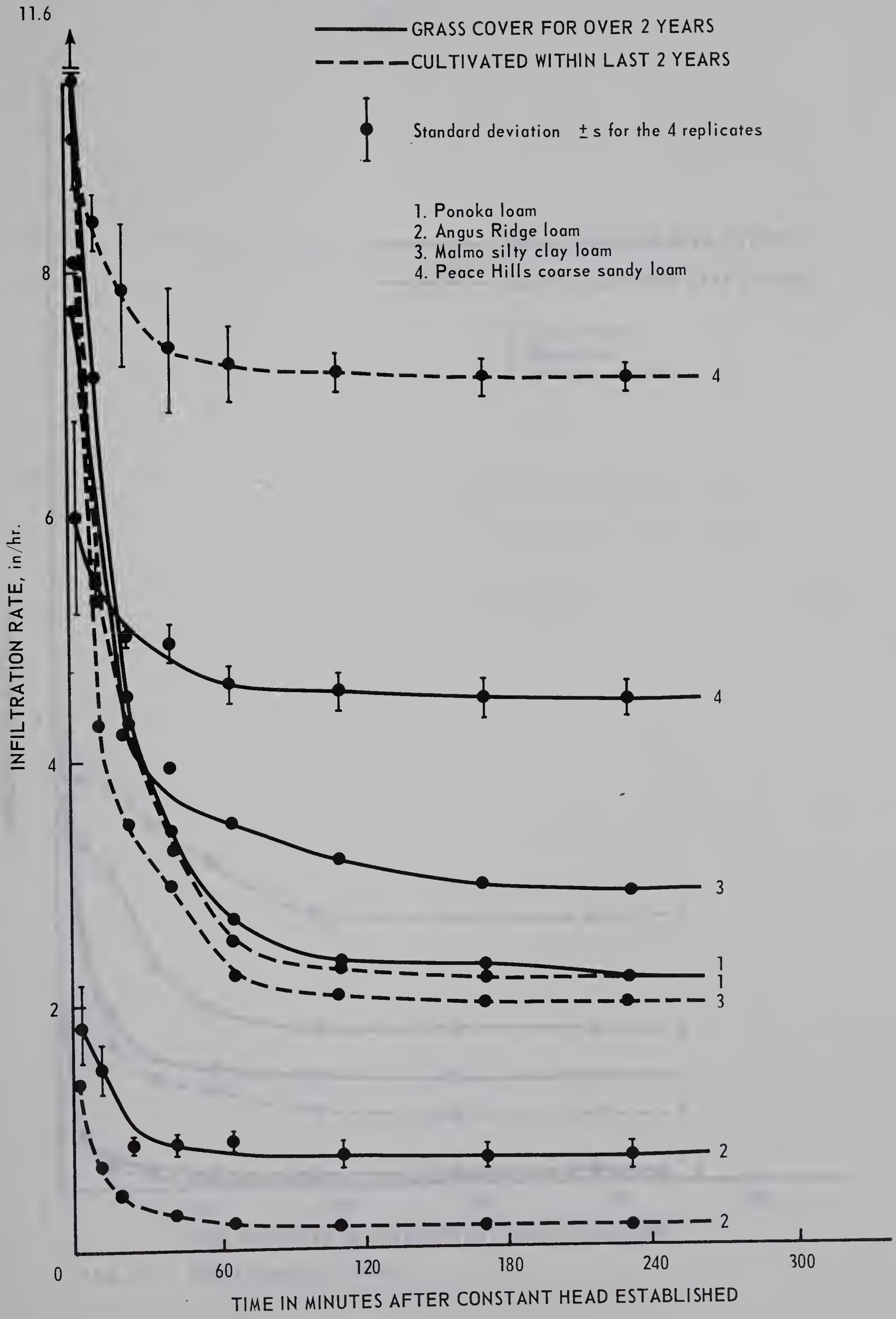

Fig. 5. Infiltration curves.

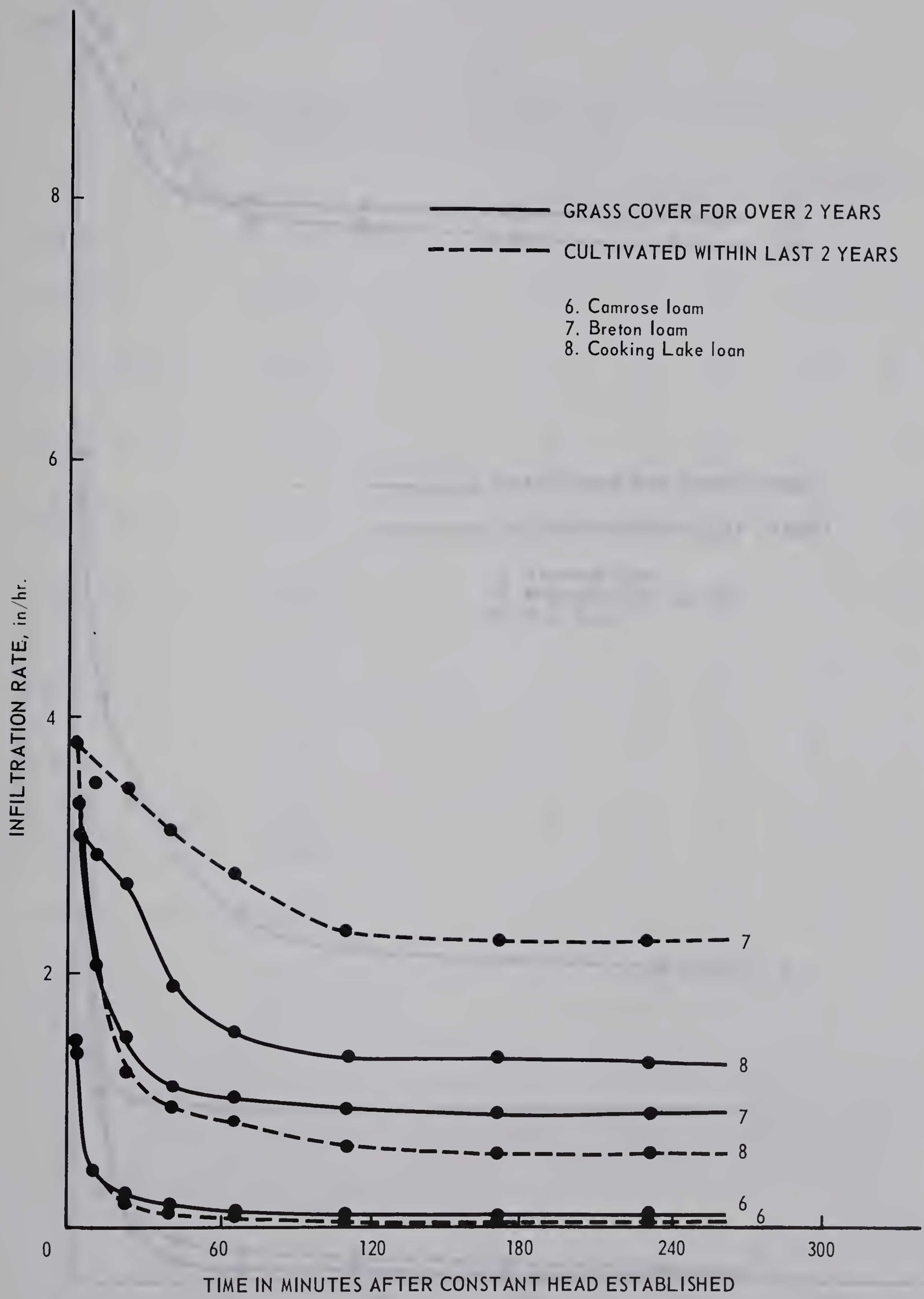

Fig. 6. Infiltration curves.

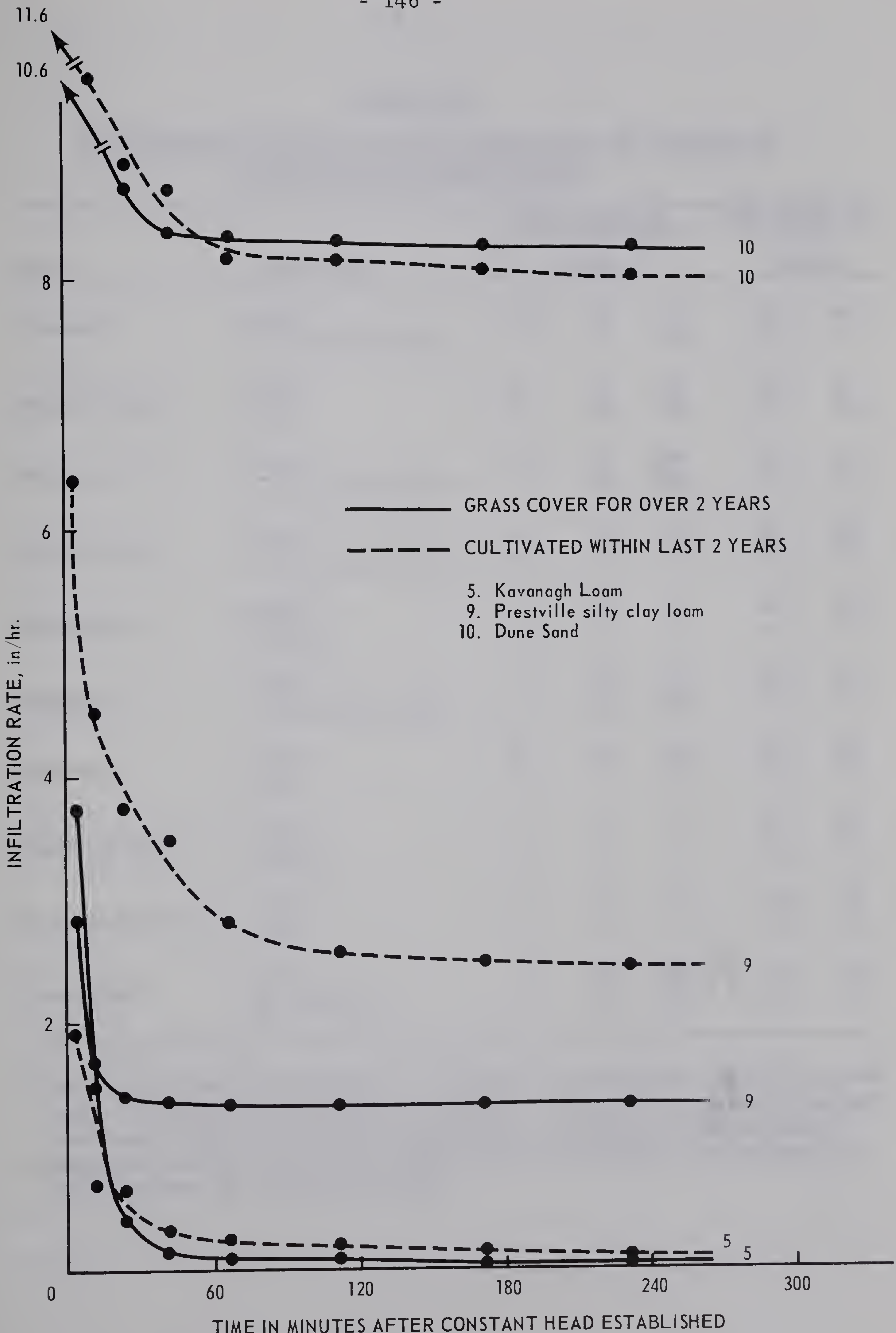

Fig. 7. Infiltration curves.

TABLE VIII

Soil Moisture Content and Soil Temperature at the Time of Measuring Infiltration Rates

Soil	Vegetation	Soil moisture 0-4	4-8	8-12	Soil Temp. C. 1-6	
		inches			inches	
Ponoka L	grass	13*	38	11	24	18
	cultivated fallow	0	1	40	26	21
Angus Ridge L	grass	16	91	100	29	22
	wheat	25	38	68	30	20
Malmo Si C L	grass	0	0	100	20	19
	cultivated fallow	0	69	100	19	18
Peace Hills	grass	0	0	13	27	18
	cultivated fallow	0	0	0	28	18
Kavanagh L	grass	0	0	0	26	22
	alfalfa	0	0	0	24	22
Camrose L	grass	1	52	25	30	21
	cultivated fallow	84	98	100	25	18
Breton L	grass	10	41	58	24	20
	oats	0	3	23	28	18
Cooking Lake L	grass	0	15	0	29	23
	barley	0	0	0	31	21
Prestville SiCL	grass	0	0	0	30	20
	oats	0	0	9	26	19
Dune Sand	grass	0	55	100	25	20
	hay pasture	0	15	100	26	21

*The water present expressed as a percent of available capacity of the soil. For those soils with a value of 0 indicated, moisture content was below the 15-atmosphere percentage. A value of 100 means the moisture content was at or above the 1/3-atmosphere percentage (or 1/10 in case of the sandy soils).

of infiltration. Table VIII shows the initial moisture content of soils in terms of available water capacity. Most of the soils were below or near the 15-atmosphere percentage in the 0-4 inches horizon and only a few were at 1/3-atmosphere (1/10-atmosphere used for sand) in the 8-12 inches horizon. The infiltration rates dueing the first minute, which are omitted from the figures, because of their extremely high values, were lower in the grass-covered soils than in recently cultivated soils, with only one exception. In this case, Kavanagh Loam, the grass-covered soil was extremely dry with many cracks. After a steady rare of infiltration was reached the rates for five, or possibly six, of the grass-covered soils were higher than for their recently cultivated counterparts. A more porous profile as a result of grass root development is no doubt an explanation.

In comparing rainfall intensity with the infiltration rates (Verma and Toogood, 1968), it is clear that many of the soils in the Edmonton area will readily absorb rain falling at the maximum one-hour intensities likely to occur in the Edmonton area. All one-hour intensities reported were less than 1.46 inches per hour, and 79 percent were less than 0.46 inches per hour. Only on the Solonetzic profiles, which make up 19 percent of the Edmonton sheet, would runoff be likely to occur. Even here, however, the usual dry and cracked condition of the surface soil and hence high initial infiltration rate would counteract this hazard. Fifteen- and five-minute rainfall intensities reached much higher maxima but countering this, as far as the hazard of runoff is concerned, are these facts: large percentages (94 and 78, respectively) were less than 2 inches per hour;

duration of the heavy rainfall is short; infiltration of all soils show high rates during the first half hour; these initial infiltration rates for many soils are in excess of rainfall maxima reported. Two other factors are the moisture deficit (Laycock, 1960), a phenomenon which means that on the average our surface soils are well below field capacity and receptive to rainfall, and secondly, the tendency of maximum intensities to occur near the start of our summer storms, just at a time when infiltration rates are high.

Provided surface sealing does not occur and under normal rainfall distribution and intensities for the area, there is a very little hazard of runoff occurring in the Edmonton area. The most susceptible soils are those of the Solonetzic order but even on these soils the probability of runoff is low (Verma and Toogood, 1968).

Meteorological Studies

Actual Evapotranspiration

Table IX shows the measured values of actual evapotranspiration during the summer of 1967 at ten sites located on different soil types in the area. The data show a large variability in actual evapotranspiration from one site to another. The variability is also evident in actual evapotranspiration rates for different months at the same site. Dune Sand and Ponoka Loam, respectively, showed the lowest and highest values of actual evapotranspiration. The rate of actual evapotranspiration is mainly controlled by the availability of moisture and heat; however, in areas of short moisture supply, the availability of soil moisture is probably the dominant factor. The moisture supply for

actual evapotranspiration mainly consists of available soil moisture in the beginning of the season and the amount of precipitation during the season. Since both of these sources of moisture supply varied from one site to another (Tables IV and IX), the variation in the amounts of actual evapotranspiration was expected.

Potential Evapotranspiration

Potential evapotranspiration, the loss of moisture from an actively growing vegetation, never short of moisture supply and covering the soil surface, can only be estimated if the amount of energy used in this process is considered with sufficient accuracy. Among various procedures, namely the Thornthwaite, Blaney-Criddle, Lowry-Johnson, and the Penman method, the latter is the only one which is based on energy balance and aerodynamic approaches to estimate the moisture losses under potential conditions. The validity of the Penman method for the estimation of potential evapotranspiration has also been confirmed by Van Bavel (1956), Levine (1959), Stanhill (1961), Decker (1962), Brutsaert (1965) and Stern (1967a).

The monthly estimates of potential evapotranspiration (by using the Penman method) for six meteorological stations are given in Table X. The data shown in this table are based on thirteen years of meteorological observations (1955-1967) at each station with the exception of the Edmonton International Airport which had only seven years of data (1961-1967) available. More detailed data on monthly evapotranspiration at these stations are given in Appendix D.

The data show very little difference in mean total potential

TABLE IX

Actual Evapotranspiration at Different Sites
(Summer, 1967)
(Inches)

Site		May (16-31)	June	July	Aug.	Sept.	Total
T (Angus Ridge	A.E.	1.6	3.1	2.4	2.9	0.8	10.8
Loam)	Ppt.	1.42	1.89	1.63	2.56	0.05	7.55
Z (Malmo Silty	A.E.	0.9	2.0	2.5	2.7	1.1	9.2
Clay Loam)	Ppt.	0.40	1.54	2.33	2.28	0.09	6.64
G (Peace Hills	A.E.	0.9	3.7	2.9	1.5	0.4	9.4
Coarse Sandy Loam)	Ppt.	0.95	2.43	1.63	1.37	0.17	6.55
E (Ponoka Loam)	A.E.	1.6	3.0	4.9	4.8	1.4	15.7
	Ppt.	1.77	2.12	1.94	1.67	0.31	7.81
F (Breton Loam)	A.E.	1.2	3.3	3.8	2.9	1.2	12.4
	Ppt.	0.79	2.65	1.58	1.88	0.02	6.92
K (Cooking Lake	A.E.	1.3	2.6	2.7	2.6	0.6	9.8
Loam)	Ppt.	1.08	2.10	1.34	1.27	0.53	6.32
V (Camrose Loam)	A.E.	1.3	2.8	2.0	2.6	0.5	9.2
	Ppt.	0.95	2.43	1.63	1.37	0.17	6.55
B (Kavanagh Loam)	A.E.	1.1	3.3	2.0	1.5	1.1	9.0
	Ppt.	0.92	2.26	1.63	1.60	0.44	6.85
O (Prestville	A.E.	1.5	3.3	4.1	2.8	0.4	12.1
Silty Clay Loam)	Ppt.	1.45	1.71	2.47	1.42	0.30	7.35
Q (Dune Sand)	A.E.	0.4	2.2	1.7	2.4	0.4	7.1
	Ppt	0.26	1.54	1.65	1.37	0.46	5.20

TABLE X

Average Monthly Potential Evapotranspiration
(1955-1967)
(Inches)

Station	May	June	July	Aug.	Sept.	Total
Calmar	3.9	4.2	4.4	3.1	1.7	17.3
Camrose	3.9	4.2	4.4	3.2	1.7	17.4
Edmonton (Industrial Airport)	4.1	4.5	4.6	3.3	1.8	18.3
Edmonton (International Airport)	3.6	4.2	4.3	3.2	1.7	17.0
Ranfurly	4.0	4.4	4.6	3.4	1.8	18.2
Sion	4.0	4.3	4.4	3.2	1.7	17.6

evapotranspiration (May to September) at different stations. The mean monthly potential evapotranspiration increases slightly from May to July with a maximum in July, and then decreases sharply in the months of August and September.

Laycock (1967) has also estimated the potential evapotranspiration for the Prairie Provinces by using the Thornthwaite method and showed that the Edmonton area had a potential evapotranspiration range between 20 and 22 inches. His values of potential evapotranspiration are higher than those calculated by using the Penman method. The data may show an increase if the potential evapotranspiration for the months of April and October is added to this total of five months (May to September). However, the values would still be low when compared to those calculated by Laycock (1967). The potential evapotranspiration for the months of April and October would be very little because of low mean monthly temperature for these months. This comparison shows that the Thornthwaite method slightly overestimates the potential evapotranspiration values for this region.

Actual Evapotranspiration as Related to Available Soil Moisture and Potential Evapotranspiration

The rate of actual evapotranspiration is mainly determined by the moisture characteristics of soil, the physiological characteristics of plants, including their rooting habits, and meteorological conditions as reflected in potential evapotranspiration rate. Therefore, actual evapotranspiration rate, as a percentage of potential

evapotranspiration rate versus abailable soil moisture as a percentage of total available water capacity, should be in a linear relationship. This has also been mentioned by Thornthwaite and Mater (1955), Slatyer (1956), Smith (1959), and Denmead and Shaw (1962).

This linear relationship between actual evapotranspiration as a percentage of potential evapotranspiration and available soil moisture as a percentage of total available water capacity was tested for the data on measured actual evapotranspiration, potential evapotranspiration (estimated by the Penman method), available soil moisture and total available water capacity values at ten sites on different soil types in the Edmonton for summer, 1967. The plot of the data (Fig. 8) show a poor fit for the linear relationship between these two parameters. Soils, such as Kavanagh Loam, Malmo Silty Clay Loam and Prestville Silty Clay Loam, with high available water capacity values had a very low A.W./A.W.C. ratio but the frequent rainfall gave enough moisture to bring the upper few inches of the soil up to or near the field capacity and to maintain quite high evapotranspiration losses. Moreover, in the beginning of the season the lower horizons of these soils were not at field capacity and therefore reduced the A.W./A.W.C. ratio of the soil profile as a whole. Meanwhile the moisture content in the upper horizon would have been near field capacity, high enough to maintain evapotranspiration at the potential rate for a short period. Soils, such as Dune Sand Peace Hills Coarse Sandy Loam, with extremely low available water capacity values showed a very high A.W./A.W.C. ratio

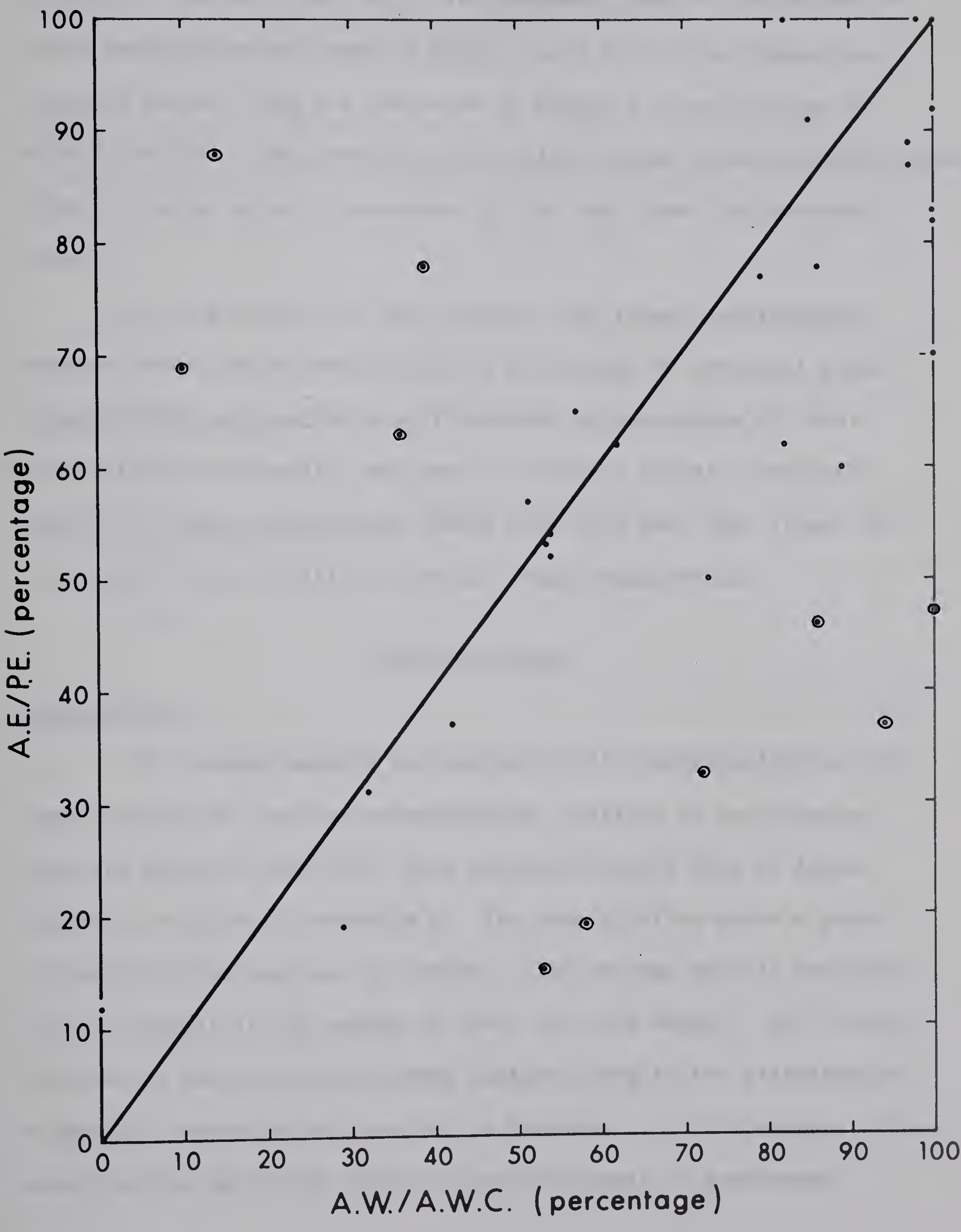

Fig. 8. Relationship between A.E./P.E. and A.W./A.W.C. The straight line is the theoretical linear relationship if perfect correlation is assumed.

but did not have enough available soil moisture to maintain the actual evapotranspiration at potential rate for significant period of time. Therefore, the data from soils with extremely high or low values of total available water capacity show a poor fit to the linear relationship curve. They are indicated in Figure 8 by encircling the points involved. The data from soils with average total available water capacity values gave a reasonable fit for the linear relationship curve.

For the purpose of this project, the linear realtionship between actual evapotranspiration as percentage of potential evapotranspiration and available soil moisture as percentage of total available water capacity, was used to estimate actual evapotranspiration. Janes and Brumbach (1966) have also used this linear relationship for calculation of actual evapotranspiration.

Moisture Balance

Precipitation

The average monthly and average total precipitation for the summer months at the five meteorological stations in the Edmonton area are given in Table XI. More detailed monthly data at these stations are given in Appendix E. The precipitation shows a great variability from one year to another. The average monthly precipitation is highest in the months of June, July and August. All the six stations in the area seem to have similar trend in the distribution of monthly precipitation from May to September. On the average, the precipitation increased slightly from north-east to south-west.

TABLE XI

Average Monthly Precipitation
(1955-1967)
(Inches)

Station	May	June	July	Aug.	Sept.	Total
Calmar	1.61	2.81	2.88	2.88	1.89	12.07
Camrose	1.52	2.58	2.97	2.65	1.54	11.26
Edmonton (Industrial Airport)	1.42	2.59	2.81	2.83	1.65	11.30
Edmonton (International Airport)	1.58	2.78	3.80	2.30	1.44	11.98
Ranfurly	1.43	2.69	3.02	2.77	1.69	11.60
Sion	1.60	2.78	2.53	2.66	1.83	11.40

Calmar had the maximum precipitation (12.07 inches) while Camrose showed the lowest (11.26 inches),

In the mean annual precipitation map (Laycock, 1967), values for the study area lie between 16 and 20 inches, with an increasing trend from east to west.

It is assumed that the precipitation data recorded at each of the meteorological stations are reasonably correct and representative of the precipitation in the surrounding areas. The Edmonton International Airport had data only from 1961 onward and therefore the mean monthly values of precipitation are not quite as meaningful as those from the other meteorological stations in the area.

Moisture Balance in the Soils of the Edmonton Area

The moisture balance patterns in the major soil types (grouped onto 9 categories on the basis of available water capacity) were estimated. The estimations had to be made for each of six meteorological stations, since the soil types having a particular available water capacity value are scattered all over the Edmonton sheet. By doing this, it was not only possible to estimate the moisture balance patterns for all the different soil types in the area, but also to assess the moisture balance patterns of soil type or types existing under different climatic variables, namely precipitation, wind and potential evapotranspiration.

Table XII shows the moisture balance patterns in the different soils of the Edmonton area. The actual evapotranspiration varied not only between the soils of different available water capacity but

TABLE XII

Moisture Balance in Soil of the Edmonton Area
(1955 - 67) Average

Available water capacity: 2 inches
Soil types: Culp Loam and Dune Sand

Station	Components	May	June	July	Aug.	Sept.	Total
	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
Calmar	A.E.	3.6	2.8	2.9	2.9	1.6	13.8
	Deficit	0.3	1.4	1.5	0.2	0.1	3.5
	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
Camrose	A.E.	3.5	2.6	3.0	2.0	1.3	13.0
	Deficit	0.4	1.6	1.4	0.6	0.4	4.4
Edmonton	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
(Ind. Air-	A.E.	3.4	2.6	2.8	2.8	1.4	13.4
port)	Deficit	0.7	1.5	1.8	0.5	0.4	4.9
Edmonton	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
(Int. Air-	A.E.	3.6	2.8	3.8	2.3	1.2	13.7
port)	Deficit	0.0	1.4	0.5	0.9	0.5	3.3
	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
Ranfurly	A.E.	3.4	2.7	3.0	2.8	1.5	13.8
	Deficit	0.6	1.3	1.6	0.6	0.3	4.4
	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
Sion	A.E.	3.6	2.8	2.5	2.7	1.5	13.1
	Deficit	0.4	1.5	1.9	0.5	0.2	4.5

(Continued)

TABLE XII. (Continued)

Available water capacity: 4 inches
Soil types: Leith Sandy Loam and Peace Hills Coarse Sandy Loam

Station	Components	May	June	July	Aug.	Sept.	Total
Calmar	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
	A.E.	3.9	4.2	3.2	2.2	1.1	14.6
	Deficit	0.0	0.0	1.2	0.9	0.6	2.7
Camrose	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
	A.E.	3.9	4.2	3.3	2.9	0.9	15.2
	Deficit	0.0	0.0	1.1	0.3	0.8	2.2
Edmonton (Industrial Airport)	P.E.	4 1	4.5	4.6	3.3	1.8	18.3
	A.E.	4.1	3.9	2.8	2.3	0.8	13.9
	Deficit	0.0	0.6	1.8	1.0	1.0	4.4
Edmonton (International Airport)	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
	A.E.	3.6	4.2	4.3	1.9	0.8	14.8
	Deficit	0.0	0.0	0.0	1.3	0.9	2.2
Ranfurly	P.E.	4.0	4.4	4.6	3.4	1.8	17.2
	A.E.	4.0	4.1	3.0	2.4	0.9	14.4
	Deficit	0.0	0.3	1.6	1.0	0.9	3.8
Sion	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
	A.E.	4.0	4.3	2.6	2.2	1.0	14.1
	Deficit	0.0	0.0	1.8	1.0	0.7	3.5

(Continued)

TABLE XII. (Continued)

Available water capacity: 6 inches
Soil type: Peace Hills Sandy Loam

Station	Components	May	June	July	Aug.	Sept.	Total
Calmar	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
	A.E.	3.9	4.2	3.8	2.2	1.1	15.2
	Deficit	0.0	0.0	0.6	0.9	0.6	2.1
Camrose	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
	A.E.	3.9	4.2	3.6	2.6	0.8	15.1
	Deficit	0.0	0.0	0.8	0.6	0.9	2.3
Edmonton (Industrial Airport)	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
	A.E.	4.1	4.4	3.3	2.1	1.0	14.9
	Deficit	0.0	0.1	1.3	1.2	0.8	3.4
Edmonton (International Airport)	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
	A.E.	3.6	4.2	4.3	2.3	1.0	15.4
	Deficit	0.0	0.0	0.0	0.9	0.7	1.6
Ranfurly	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
	A.E.	4.0	4.4	3.6	2.2	1.0	15.2
	Deficit	0.0	0.0	1.0	1.2	0.8	3.0
Sion	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
	A.E.	4.0	4.3	3.4	2 1	1.0	14.8
	Deficit	0.0	0.0	1.0	1.1	0.7	2.8

(Continued)

TABLE XII. (Continued)

Available water capacity: 8 inches
Soil types: Angus Ridge Loam and Breton Loam

Station	Components	May	June	July	Aug.	Sept.	Total
Calmar	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
	A.E.	3.9	4.2	4.0	2.4	1.2	15.7
	Deficit	0.0	0.0	0.4	0.7	0.5	1.6
Camrose	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
	A.E.	3.9	4.2	3.9	2.3	1.0	15.3
	Deficit	0.0	0.0	0.5	0.9	0.7	2.1
Edmonton (Industrial Airport)	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
	A.E.	4.1	4.4	3.6	2.3	1.1	15.5
	Deficit	0.0	0.1	1.0	1.0	0.7	2.8
Edmonton (Internationa Airport)	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
	A.E.	3.6	4.2	4.3	2.6	1.1	15.8
	Deficit	0.0	0.0	0.0	0.6	0.6	1.2
Ranfurly	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
	A.E.	4 0	4.4	3.9	2.4	1.1	15.8
	Deficit	0.0	0.0	0.7	1.0	0.7	2.4
Sion	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
	A.E.	4.0	4.3	3.6	2.3	1.1	15.3
	Deficit	0.0	0.0	0.8	0.9	0.6	2.3

(Continued)

TABLE XII. (Continued)

Available water capacity: 9 inches
Soil types: Alluvium Sandy Loam, Camrose Loam, Falun Loam, Malmo Silty Clay Loam, Navarre Silty Clay Loam, Uncas Loam, Wetaskiwin Silty Clay Loam, and Winterburn Loam

Station	Components	May	June	July	Aug.	Sept.	Total
	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
Calmar	A.E.	3.9	4.2	4.0	2.4	1.2	15.7
	Deficit	0.0	0.0	0.4	0.7	0.5	1.6
	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
Camrose	A.E.	3.9	4.2	3.9	2.4	1.1	15.5
	Deficit	0.0	0.0	0.5	0.8	0.6	1.9
Edmonton	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
(Industrial	A.E.	4.1	4.4	3.7	2.3	1.1	15.6
Airport)	Deficit	0.0	0.1	0.9	1.0	0.7	2.7
Edmonton	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
(International	A.E.	3.6	4.2	4.2	2.6	1.2	15.8
Airport)	Deficit	0.0	0.0	0.1	0.6	0.5	1.2
	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
Ranfurly	A.E.	4.0	4.4	4.0	2.4	1.2	16.0
	Deficit	0.0	0.0	0.6	1.0	0.6	2.2
	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
Sion	A.E.	4.0	4.3	3.7	2.3	1.2	15.5
	Deficit	0.0	0.0	0.7	0.9	0.5	2.1

(Continued)

TABLE XII. (Continued)

Available water capacity: 10 inches
Soil types: Cooking Lake Loam, Ponoka Loam and Prestville Silty Clay Loam

Station	Components	May	June	July	Aug.	Sept.	Total
	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
Calmar	A.E.	3.9	4.2	4.0	2.5	1.3	15.9
	Deficit	0.0	0.0	0.4	0.6	0.4	1.4
	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
Camrose	A.E.	3.9	4.2	4.0	2.4	1.1	15.6
	Deficit	0.0	0.0	0.4	0.8	0.6	1.8
Edmonton	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
(Industrial	A.E.	4.1	4.5	3.8	2.4	1.2	16.0
Airport)	Deficit	0.0	0.0	0.8	0.9	0.6	2.3
Edmonton	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
(International	A.E.	3.6	4.2	4.3	2.7	1.2	16.0
Airport)	Deficit	0.0	0.0	0.0	0.5	0.5	1.0
	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
Ranfurly	A.E.	4.0	4.4	4.0	2.6	1.2	16.2
	Deficit	0.0	0.0	0.6	0.8	0.6	2.0
	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
Sion	A.E.	4.0	4.3	3.8	2.4	1.2	15.7
	Deficit	0.0	0.0	0.6	0.8	0.5	1.9

(Continued)

TABLE XII. (Continued)

Available water capacity: 11 inches
Soil type: Duagh Silty Clay Loam and Maywood Silty Clay Loam

Station	Components	May	June	July	Aug.	Sept.	Total
Calmar	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
	A.E.	3.9	4.2	4.1	2.5	1.3	16.0
	Deficit	0.0	0.0	0.3	0.6	0.4	1.3
Camrose	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
	A.E.	3.9	4.2	4.0	2.5	1.2	15.8
	Deficit	0.0	0.0	0.4	0.7	0.5	1.6
Edmonton (Industrial Airport)	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
	A.E.	4.1	4.4	3.9	2.4	1.2	16.0
	Deficit	0.0	0.1	0.7	0.9	0.6	2.3
Edmonton (International Airport)	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
	A.E.	3.6	4.2	4.3	2.7	1.2	16.0
	Deficit	0.0	0.0	0.0	0.5	0.5	1.0
Ranfurly	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
	A.E.	4.0	4.4	4.0	2.6	1.2	16.2
	Deficit	0.0	0.0	0.6	0.8	0.6	2.0
Sion	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
	A.E.	4.0	4.3	3.8	2.5	1.2	15.7
	Deficit	0.0	0.0	0.6	0.7	0.5	1.9

(Continued)

TABLE XII. (Continued)

Available water capacity: 12 inches
Soil type: Mico Silty Clay Loam

Station	Components	May	June	July	Aug.	Sept.	Total
	P.E.	3.9	4.2	4.4	3.1	1 7	17.3
Calmar	A.E.	3.9	4 2	4.1	2.6	1.3	16.1
	Deficit	0.0	0.0	0.3	0 5	0.4	1.2
	P.E.	3.9	4.2	4.4	3.2	1 7	17.4
Camrose	A.E.	3.9	4.2	4 0	2.6	1.2	15.9
	Deficit	0.0	0.0	0.4	0 6	0 5	1.5
Edmonton	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
(Industrial	A.E.	4.1	4.4	4.0	2.5	1.2	16.2
Airport)	Deficit	0.0	0.1	0.6	0.8	0.6	2.1
Edmonton	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
(International	A.E.	3.6	4.2	4.3	2.8	1.3	16.2
Airport)	Deficit	0.0	0.0	0.0	0.4	0.4	0.8
	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
Ranfurly	A.E.	4.0	4.4	4.1	2.6	1.3	16.4
	Deficit	0.0	0.0	0.5	0.8	0.5	1.8
	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
Sion	A.E.	4.0	4.3	3.9	2.5	1.2	15.9
	Deficit	0.0	0.0	0.5	0.7	0.5	1.7

(Continued)

TABLE XII. (Continued)

Available water capacity: 18 inches (value questioned see page 103)
Soil type: Kavanagh Loam

Station	Components	May	June	July	Aug.	Sept.	Total
	P.E.	3.9	4.2	4.4	3.1	1.7	17.3
Calmar	A.E.	3.9	4.2	4.2	2.7	1.4	16.4
	Deficit	0.0	0.0	0.2	0.4	0.3	0.9
	P.E.	3.9	4.2	4.4	3.2	1.7	17.4
Camrose	A.E.	3.9	4.2	4.1	2.8	1.3	16.3
	Deficit	0.0	0.0	0.3	0.4	0.4	1.1
Edmonton	P.E.	4.1	4.5	4.6	3.3	1.8	18.3
(Industrial	A.E.	4.1	4.4	4.1	2.7	1.4	16.7
Airport)	Deficit	0.0	0.1	0.5	0.6	0.4	1.6
Edmonton	P.E.	3.6	4.2	4.3	3.2	1.7	17.0
(International	A.E.	3.6	4.2	4.3	2.9	1.4	16.4
Airport)	Deficit	0.0	0.0	0.0	0.3	0.3	0.6
	P.E.	4.0	4.4	4.6	3.4	1.8	18.2
Ranfurly	A.E.	4.0	4.4	4.3	2.8	1.4	16.9
	Deficit	0.0	0.0	0.3	0.4	0.4	1.3
	P.E.	4.0	4.3	4.4	3.2	1.7	17.6
Sion	A.E.	4.0	4.3	4.0	2.7	1.4	16.4
	Deficit	0.0	0.0	0 4	0.5	0.3	1.2

also between the different meteorological stations. This is mainly due to variation in precipitation and potential evapotranspiration values at these stations.

Moisture Deficit

Average moisture deficit patterns for differnt soil types of the Edmonton area are shown in Table XII. The average values of moisture deficit are based on thirteen years of meteorological data at all the stations except at the Edmonton International Airport which had only seven years of data available.

The moisture deficits varied from 4.9 inches in soil of very low water-holding capacity (2 inches), such as Culp Loam and Dune Sand, to less than one inch in Mico Silty Clay Loam and Kavanagh Loam soils which had very high available water capacity (12 and 18 inches). For average precipitation, the moisture deficit generally decreased with an increase in available water capacity of soils.

The values of moisture deficit also varied from one station to another. The pattern showed a slight increased from south-east to north-west. This could be due to a similar variation trend in precipitation patterns and/or due to reverse variation trend in potential evapotranpiration patterns in the area.

In years of above normal precipitation during the growing season, the variation in moisture deficit values in soils of different available water capacities would be less, but in years of higher rainfall and winter precipitation, the variation would be greater. This would be due to the greater amount of available moisture in soils of higher available water capacity values.

The soils with low available water capacity values showed a moisture deficit right from the beginning of the growing season. The deficit was not evident in soils of high available water capacity till the month of July or even later in some cases. This could be due mainly to the greater amount of available moisture in soils of higher available water capacity. This pattern might change significantly in the years of above normal precipitation during the early stage of the growing season.

Though all the soils had moisture deficits in the months of August and September, the soils with low available water capacity values showed greater deficits as compared to those with higher available water capacity values.

SUMMARY AND CONCLUSION

The available water capacities in the major soil types of the Edmonton area were determined for the purpose of estimating moisture balance patterns in the area. From the foregoing results and discussion, it is evident that the soils of the Edmonton area had marked differences in their moisture balance patterns.

The soil types showed significant differences in their available water capacities. Kavanagh Loam had a very high available water capacity value. In general, the silty clay loam soils had higher available water capacities as compared to loam, sandy loam and sandy soils.

The available water capacity of a soil is affected by the physical, chemical and pedological properties of its profile. The values of available water capacity showed high positive correlations with field capacity, permanent wilting point, silt percentage, and coarse clay. The correlation between available water capacity and sand was negative but significant. There was a poor relationship between available water capacity and bulk density and a similar relationship existed between available water capacity and soil organic-matter. The multiple correlations between available water capacity and the different physical variables of the soil profile were very high. Prediction equations were developed with the aid of multiple regression analysis to estimate the available water capacity from the known variables of soil profile.

The twenty-two major soil types of the Edmonton area were

grouped into nine different categories of available water capacity. The range of available water capacity was from 2 to 18 inches with most of the soils having values of 8 to 12 inches per four feet.

In comparing rainfall intensity with the infiltration rates, it is clear that most of the soils in the Edmonton area will readily absorb rain falling at the maximum one-hour intensities likely to occur in the Edmonton area. Runoff may occur on the solonetzic soils; even here, however, the usual dry and cracked condition of the soil, and hence high initial infiltration rate would counteract this hazard. Provided surface sealing does not occur and under normal rainfall distribution and intensities for the area, there is a very small hazard of runoff occurring in the Edmonton area.

The measured values of actual evapotranspiration of ten different soil types in the Edmonton area during the summer of 1967 were smaller than those estimated from the average potential evapotranspiration, available water capacity and precipitation data. Since the precipitation during the summer of 1967 was well below normal, this variation was expected.

The estimates of potential evapotranspiration (using the Penman method showed very little difference when mean monthly values and the totals for the whole summer (May to September) at different stations were compared. The maximum potential evapotranspiration occurred in the month of June and July. These two months also showed maximum mean monthly precipitation.

The data did not show a good linear relationship between the ratios A.E./P.E. and A.W./A.W.C.

However, the linear relationship between these two was used in this study for the estimation of actual evapotranspiration from potential evapotranspiration, available soil moisture and total available water capacity data.

The precipitation distribution in the Edmonton area varied from one station to another. On the average, the total precipitation for the summer months increased slightly from northeast to southwest. The mean monthly values of precipitation at different stations also showed some variability.

The estimated actual evapotranspiration revealed the effect of available water capacities, potential evapotranspiration and precipitation. The values of actual evapotranspiration increased with an increase in available water capacity.

The moisture deficit patterns had a negative relationship with available water capacity and precipitation. The amount of deficit was high in soils of low available water capacity. In soils of medium available water capacity, with normal precipitation, the moisture area had a deficit of about two inches. The amount varied according to the variation in precipitation.

Evaluation of the results from this study and those from previous investigations reported in the literature, point out several common inadequacies in our basic understanding of vegetation-soil-water interrelationships. Furthermore, the relationships between soil-moisture availability, vegetation growth, and evapotranspiration are inadequately understood. Research in these areas is not only

basic to soil science and agriculture, but also to hydrology, to forestry, and to intelligent management of our forested and agricultural lands in meeting the needs of the present and future generation.

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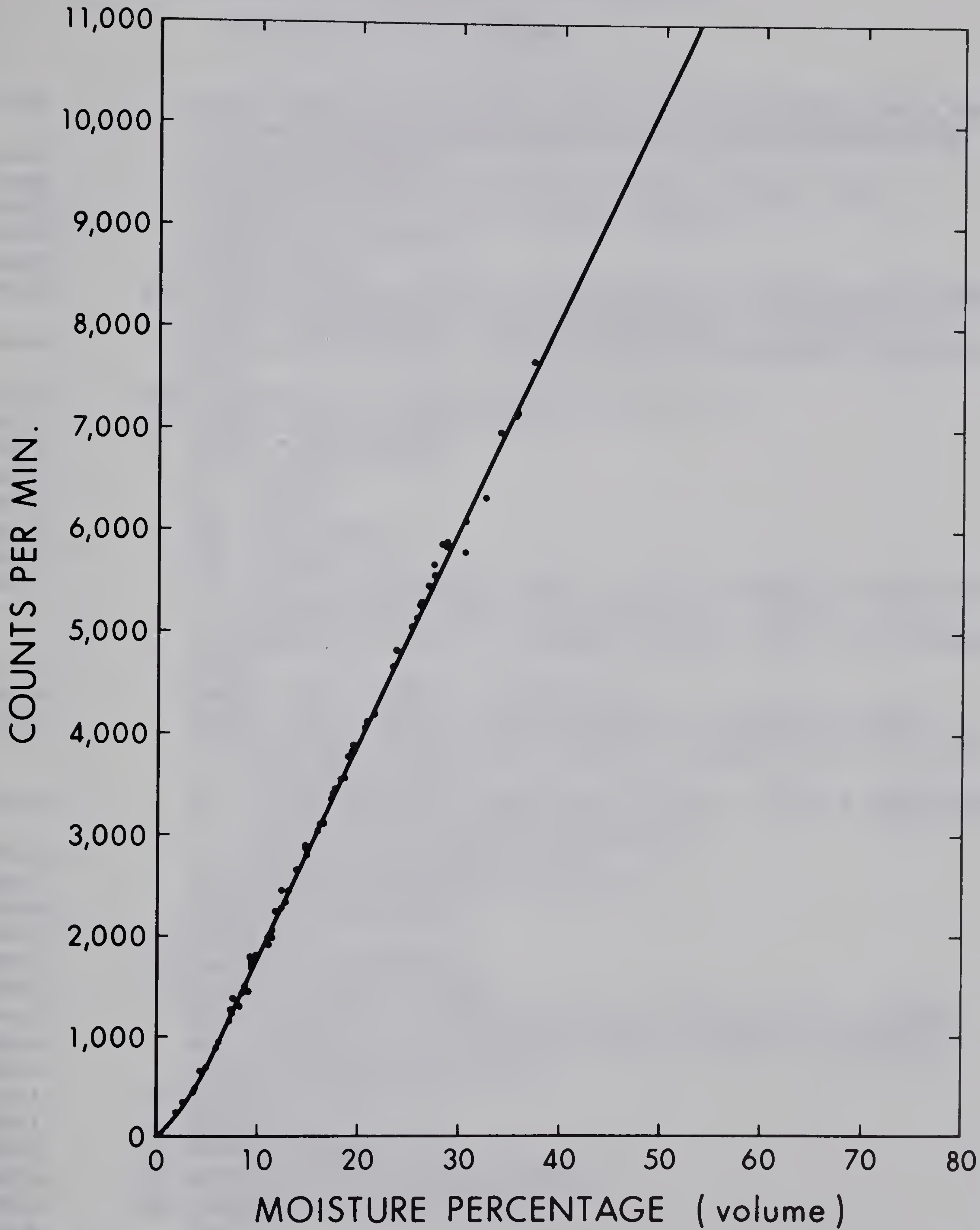
APPENDIX A

Analysis of Variance for Available Water Capacity

Source of variation	S.S.	D.F.	F	Remark
Soil types	1387.9	27	135.3*	Highly significant
Replicates	0.3	4	0.07	
Error	40.6	108	0.38	
Total	1428.8	139		

* Significant at 1 percent level.

APPENDIX B



Calibration Curve for the Neutron Moisture Probe.

APPENDIX C

Program for estimating P.E. by the Penman Method

(OS/360 Fortran H - Verma)

```
ISN 0002           REAL*8 TMAX,TMIN,RHO5,RH17,WIND,RADIN,SUN,EDSUN(5),TMEAN,TEMP,
                   TS,1 WS,TST,TTS,EW,EDAVE,DELTA,RB,H,EA,ZRATIO,EUCALC,EA,DP
ISN 0003           INTEGER*4 STN,MO,YR
ISN 0004           DATA EDSUN/15,9903, 17.0366, 16.5354, 14.8064, 12.7/
ISN 0005           TCALC(F)= ((5./9.) * (F - 32.)) + 273.16
ISN 0006           ZRATIO = 0.7239360793
ISN 0007           WRITE(6,999)
ISN 0008       999 FORMAT('1PENMAN POTENTIAL EVAPORATION'///'OSTATION YEAR MONTH
                   MEAN 1 EVAPORATION'/' ',19X,'TEMPERATURE  IN INCHES'////)
ISN 0009         5 READ(5,1000,END=100) STN,MO,YR,TMAX,TMIN,RHO5,RH17,WIND,RADIN,
                   SUN
ISN 0010      1000 FORMAT(11,12,13,2F3.0,6X,2F3.2,2F4.0,F4.1)
ISN 0011           TMEAN= (TMAX + TMIN) / 2.
ISN 0012           TEMP = TCALC(TMEAN)
ISN 0013           TS = 370.92
ISN 0014           WS = 935.0
ISN 0015           TST = TS / TEMP
ISN 0016           TTS = TEMP / TS
ISN 0017           EW = 10. ** ((-7.90298 * (TST - 1.)) + (5.02808 * DLOG10(TST))-
                   1 (0.00000013816 * (10. ** (11.344 * (1. - TTS)) - 1.)) +
                   (0.008132 18 * (10. ** (-3.49149 * (TST - 1.)) - 1.)) + DLOG10
                   (WS))
ISN 0018           EDAVE = EW * ((RHO5 + RH 17) / 2.)
ISN 0019           DELTA = (EW / (TEMP ** 2)) * (6790.5 - (5.02808 * TEMP) + 1
                   (4916.8 * (10. ** (-0.0304 * TEMP)) * (TEMP ** 2)) + 17.4209
                   2 - (1302.88 / TEMP))
ISN 0020           RB = 0.00000000198 * (TEMP ** 4) * (0.56 - (0.09 * DSQRT(EDAVE)))
                   1 * (0.10 + (0.90 * (SUN / EDSUN(MO))))
ISN 0021           H = (RADIN * 0.01271186) - RB
ISN 0022           IF (YR.GT.60.AND.STN.LE.3) GO TO 10
ISN 0024           ZRATIO = 0.6489751063
ISN 0025           GO TO 15
ISN 0026        10 ZRATIO = 0.7239360793
ISN 0027        15 EUCALC = ZRATIO * WIND
ISN 0028           EA = 0.35 * (1. + (EUCALC / 100.)) * ((EW * 0.75) - EDAVE)
ISN 0029           EP = (((DELTA * H) + (0.62197 + EA)) / (DELTA + 0.62197))
ISN 0030           GO TO (21,20,21,21,20), MO
ISN 0031        20 EP=EP * 0.0394 * 30.
ISN 0032           GO TO 25
ISN 0033        21 EP=EP * 0.0394 * 31.
ISN 0034        25 WRITE(6,1001) STN,YR,MO,TMEAN,EP
ISN 0035      1001 FORMAT(' ',17,15,16,2F12.1)
ISN 0036           GO TO 5
ISN 0037       100 STOP
ISN 0038           END

****** END OF COMPILATION ******
```

APPENDIX D

Monthly Potential Evapotranspiration
(inches)

Calmar (1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	3.6	5.2	3.9	3.6	1.5	17.8
1956	5 4	4.5	4.4	3.0	1.3	18.6
1957	4.2	4.3	4 3	2.5	1.9	17.2
1958	4.5	4.1	4.3	3.4	1.5	17.8
1959	3.6	3.5	4 7	2.5	1.4	15.7
1960	3.5	3.7	4 6	2.8	1.8	16.4
1961	3.5	4.9	4.1	3.6	1.7	17.8
1962	3.1	4.0	3.3	2.5	1.3	14.2
1963	3.2	4.7	5.0	3.8	2.2	18.9
1964	3.9	4.7	4.9	3.3	1.4	18.2
1965	4.0	3.7	4.5	3.2	1.1	16.5
1966	4.8	4.0	4.1	2.5	1.8	17.2
1967	3.2	3.6	4.9	3.3	2.7	17.7
Mean	3.9	4.2	4.4	3.1	1.7	17.3

(Continued)

(APPENDIX D. Continued)

Camrose (1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	3.8	5.2	3.9	3.8	1.5	18.2
1956	5.2	4.6	4.6	3.1	1.4	18.9
1957	4.3	4.3	4.4	2.6	1.9	17.5
1958	4.5	4.0	4.3	3.5	1.6	17.9
1959	3.5	3.6	4.8	2.6	1.4	15.9
1960	3.5	3.7	4.6	2.9	1.8	16.5
1961	3.6	4.9	4.2	3.7	1.7	18.1
1962	3.2	3.9	3.4	2.6	1.3	14.4
1963	3.3	4.8	5.1	3.8	2.2	19.2
1964	4.0	4.7	5.0	3.4	1.4	18.5
1965	4.1	3.7	4.6	3.2	1.1	16.7
1966	4.8	4.0	4.2	2.5	1.9	17.4
1967	3.2	3.6	4.1	3.3	2.7	16.9
Mean	3.9	4.2	4.4	3.2	1.7	17.4

(Continued)

(APPENDIX D. Continued)

Edmonton Industrial Airport
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	3.7	5.4	4.0	3.9	1.6	18.6
1956	5.6	4.7	4.6	3.1	1.4	19.4
1957	4.3	4.5	4.6	2.6	1.9	17.9
1958	4.6	4.1	4.4	3.0	1.6	17.7
1959	3.6	3.6	4.9	2.6	1.4	16.1
1960	3.6	3.7	4.7	2.9	1.8	16.7
1961	3.7	4.9	4.2	3.7	1.5	18.0
1962	3.3	4.1	3.6	2.9	1.6	15.5
1963	3.4	5.1	5.5	4.2	2.4	20.6
1964	4.2	5.1	5.4	3 7	1.6	20.0
1965	4.2	4.4	5.2	3.8	1.5	19.1
1966	5.1	4.6	4.7	3.0	2.3	19.7
1967	3.7	4.2	4.7	4.1	3.1	19.8
Mean	4.1	4.5	4.6	3.3	1.8	18.3

(Continued)

(APPENDIX D. Continued)

Edmonton International Airport
(1961-1967)

Year	May	June	July	Aug.	Sept.	Total
1961	3.6	4.9	4.1	3.7	1.6	17.9
1962	3.1	4.0	3.3	2.6	1.3	14.3
1963	3.2	4.7	5.1	3.8	2.2	19.0
1964	3.9	4.6	4.9	3.3	1.4	18.1
1965	4.0	3.6	4.5	3.1	1.0	16.2
1966	4.7	3.9	4.1	2.4	1.8	16.9
1967	3.1	3.5	3.9	3.2	2.6	16.3
Mean	3.6	4.2	4.3	3.2	1.7	17.0

(Continued)

(APPENDIX D. Continued)

Ranfurly
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	3.8	5.2	3.9	3.8	1.5	18.2
1956	5.7	4.5	4.5	3.1	1.2	19.0
1957	4.3	4.3	4.5	2.5	2.0	17.6
1958	4.5	4.0	4.5	3.5	1.5	18.0
1959	3.6	3.7	4.9	2.7	1.4	16.3
1960	3.5	3.8	4.6	2.9	1.8	16.6
1961	3.6	4.7	4.1	3.7	1.6	17.7
1962	3.2	4.1	3.5	2.8	1.6	15.2
1963	3.4	5.2	5.3	4.2	2.4	20.5
1964	4.1	5.0	5.5	4.0	1.6	20.2
1965	4.2	4.5	5.0	3.7	1.5	18.9
1966	5 0	4.7	4.8	2.9	2.3	19.7
1967	3.6	4.1	4.7	4.1	3 0	19.5
Mean	4.0	4.4	4.6	3.4	1 8	18.2

(Continued)

(APPENDIX D. Continued)

Sion
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	3.6	5.2	3.9	3.8	1.5	18.0
1956	5.6	4.4	4.5	3.0	1.3	18.8
1957	4.2	4.3	4.4	2.5	1.9	17.3
1958	4.5	4.0	4.3	3.4	1.5	17.7
1959	3.5	3.4	4.6	2.5	1.3	15.3
1960	3.4	3.5	4.5	2.7	1.8	15.9
1961	3.5	4.6	4.0	3.5	1.4	17.0
1962	3.1	3.9	3.3	2.7	1.6	14.6
1963	3.3	4.9	5.3	4.0	2.2	19.7
1964	4.0	4.9	5.1	3.5	1.6	19.1
1965	4.1	4.3	5.0	3.6	1.5	18.5
1966	4.9	4.4	4.4	2.9	2.2	18.8
1967	3.7	4.1	4.6	4.0	2.9	19.3
Mean	4.0	4.3	4.4	3.2	1.7	17.6

APPENDIX E

Monthly Precipitation for Summer Months
(inches)
Calmar (1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	1.47	1.94	4.30	1.82	4.28	13.81
1956	0.51	4.30	4.23	2.63	1.94	13.61
1957	1.09	1.38	2.98	1.54	1.19	8.18
1958	1.72	2.59	1.69	2.24	4.81	13.05
1959	1.70	3.03	2.46	4.68	1.35	13.22
1960	1.56	3.34	1.22	7.24	1.25	14.61
1961	1.06	2.01	3.90	0.31	1.20	8.48
1962	1.73	3.40	2.20	2.65	1.35	11.33
1963	1.31	1.35	4.50	1.53	1.27	9.96
1964	2.92	1.58	2.38	3.07	3.54	13.49
1965	3.17	7.27	2.20	3.55	1.24	17.43
1966	1.46	1.62	2.95	4.43	1.12	11.58
1967	1.26	2.73	2.37	1.76	0.06	8.18
Mean	1.61	2.81	2.88	2.88	1.89	12.07

(Continued)

(APPENDIX E. Continued)

Camrose
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	0.59	1.07	4.25	1.26	3.16	10.33
1956	0.59	5.17	2.29	2.40	1.28	11.73
1957	1.38	2.00	1.42	5.23	1.55	11.58
1958	1.31	1.54	0.67	1.15	3.28	7.95
1959	0.67	2.20	2.51	3.59	1.54	10.51
1960	1.51	3.47	2.40	2.97	1.06	11.41
1961	1.44	1.57	4.26	0.87	1.06	9.20
1962	2.13	3.00	4.64	1.94	1.29	13.00
1963	1.11	2.53	7.99	2.26	1.11	15.00
1964	3.21	0.87	1.90	1.49	2.07	9.54
1965	3.90	5.51	2.22	3.03	1.51	16.17
1966	1.23	1.94	2.54	6.47	1.09	13.27
1967	0.74	2.61	1.49	1.81	0.05	6.70
Mean	1.52	2.58	2.97	2.65	1.54	11.26

(Continued)

(APPENDIX E. Continued)

Edmonton Industrial Airport
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	0.49	1.42	5.09	0.78	3.39	11.17
1956	0.28	5.21	2.75	4.13	1.38	13.75
1957	0.46	1.11	1.34	3.63	0.74	7.28
1958	1.02	2.30	2.37	2.83	4.13	12.65
1959	1.61	2.69	2.69	3.86	1.99	12.84
1960	2.35	2.86	3.22	3.72	2.39	14.54
1961	0.97	1.84	3.74	0.22	1.02	7.79
1962	2.25	3.07	3.17	2.26	1.02	11.77
1963	1.27	2.16	2.56	1.09	1.32	8.40
1964	2.14	1.04	2.96	2.79	2.55	11.48
1965	2.90	7.48	2.11	2.14	1.10	15.73
1966	1.11	0.89	2.45	6.44	0.34	11.23
1967	1.58	1.72	2.02	2.93	0.03	8.28
Mean	1.42	2.59	2.81	2.83	1.65	11.30

(Continued)

(APPENDIX E. Continued)

Edmonton International Airport
(1961-1967)

Year	May	June	July	Aug.	Sept.	Total
1961	0.85	2.29	5.25	0.24	1.03	9.66
1962	1.57	3.92	5.46	2.65	1.85	15.45
1963	1.42	1.31	4.49	1.69	1.65	10.56
1964	2.23	1.14	3.94	2.19	3.19	12.69
1965	2.61	6.44	3.18	2.89	1.58	16.70
1966	1.52	1.90	2.41	5.18	0.77	11.78
1967	0.84	2.43	1.84	1.85	0.03	6.99
Mean	1.58	2.78	3.80	2.38	1.44	11.98

(Continued)

(APPENDIX E. Continued)

Ranfurly
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	0.58	2.32	3.81	1.19	3.70	11.60
1956	0.54	5.27	2.86	3.81	2.88	15.36
1957	0.32	1.38	2.73	5.81	0.97	11.21
1958	1.13	1.41	1.01	2.34	4.70	10.59
1959	1.10	2.33	1.60	4.87	2.13	12.03
1960	2.40	1.80	4.07	3.30	0.83	12.40
1961	1.56	5.06	3.92	0.75	1.05	12.34
1962	2.09	4.70	6.33	1.25	1.00	15.37
1963	1.54	2.91	4.30	1.24	0.29	10.28
1964	2.52	0.56	2.17	1.21	2.99	9.45
1965	3.33	4.61	1.64	2.79	0.94	13.31
1966	0.53	0.81	2.15	5.98	0.42	9.89
1967	0.99	1.80	2.64	1.48	0.10	7.01
Mean	1.43	2.69	3.02	2.77	1.69	11.60

(Continued)

(APPENDIX E. Continued)

Sion
(1955-1967)

Year	May	June	July	Aug.	Sept.	Total
1955	0.52	1.35	4.46	1.26	3.72	11.31
1956	0.32	4.77	2.60	3.70	2.04	13.43
1957	0.45	1.20	1.68	4.31	1.59	9.23
1958	1.43	1.58	1.78	2.12	4.66	11.57
1959	1.91	4.34	1.74	4.10	1.04	13.13
1960	2.25	3.60	1.68	3.89	2.28	13.70
1961	0.82	4.74	2.63	0.70	1.51	10.40
1962	3.00	3.07	3.35	1.64	1.23	12.29
1963	1.40	0.71	2.51	1.50	1.44	7.56
1964	4.07	2.42	3.61	3.71	2.37	16.18
1965	2.37	5.29	2.35	2.55	1.02	13.58
1966	1.54	1.42	3.23	4.43	0.57	11.19
1967	0.76	1.70	1.29	0.61	0.28	4.64
Mean	1.60	2.78	2.53	2.66	1.83	11.40